FINAL REPORT

A Low-Cost, Passive Approach for Bacterial Growth and Distribution for Large-Scale Implementation of Bioaugmentation

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J. Trotsky
R. A. Wymore
M.R. Lamar
K.S. Sorenson
NAVFAC – ESC

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14. ABSTRACT

This ESTCP project compared a low-cost, passive approach for bioaugmentation to an active recirculation approach for full-scale TCE source area application. The active cell operated by continuously extracting and reinjecting groundwater, while the passive system used an "inject and drift" approach. Electron donor was added weekly for the active cell and monthly for the passive cell. After several months of pre-conditioning, bioaugmentation was performed using a commercially available culture. Results showed that dechlorination to VC with significant production of ethene, as well as distribution of DHC, was achieved in the upgradient half of the active treatment cell (more than 35 ft from injection wells), and at monitoring wells near two of the three passive cell injection locations (more than 25 ft from injection wells). Comparison of bacterial growth and transport indicated that DHC was transported almost as quickly as a conservative tracer under both flow regimes, suggesting that retardation of bacteria was not significant. Overall, bacterial growth and dechlorination performance was similar using both approaches, but the active system was more costly.

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ACRONYMS

AOC	Area of Concern
ARD	anaerobic reductive dechlorination
ASTM	American Society of Testing and Materials
ATSDR	Agency for Toxic Substances and Disease Registry
BCI	Bioremediation Consulting, Inc.
bgs	below ground surface
Cal EPA	California Environmental Protection Agency
CDM	Camp Dresser & McKee Inc.
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
cis-DCE	cis-1,2-dichloroethene
CMT	Continuous Multichannel Tubing
COC	chemicals of concern
COD	chemical oxygen demand
CPT	cone penetrometer
CSIA	carbon stable isotope analysis
d	days
DCE	1,2-dichloroethene
DHC	*Dehalococcoides* species
DNA	deoxyribonucleic acid
DNAPL	dense, non-aqueous phase liquid
DO	dissolved oxygen
DoD	Department of Defense
DQO	data quality objectives
GAC	granular activated carbon
gpm	gallons per minute
EPA	Environmental Protection Agency
ERH	electrical resistance heating
ERSE	Extended Remedial Site Evaluation
ESTCP	Environmental Security Technology Certificate Program
FS	Feasibility Study
ft/d	feet per day
FTL	field team leader
HASP	health and safety plan
HDPE	high density polyethylene
IR	Installation Restoration
ITRC	Interstate Technology Regulatory Council
L	liters
LBL	Lawrence Berkeley National Laboratory
m	meters
MCLs	maximum contaminant levels
MNA	monitored natural attenuation
µg/L	micrograms per liter

mg/L	milligrams per liter
NASA	National Aeronautics and Space Administration
NAVFAC ESC	Naval Facilities Engineering Services Command
NAVFAC SW	Naval Facilities Engineering Command Southwest
NAVWPNSTA	Naval Weapons Station
NFESC	Naval Facilities Engineering Service Center
NPL	National Priorities List
O&M	operations and maintenance
OCHCA	Orange County Health Care Agency
ORP	oxidation/reduction potential
OSHA	Occupational Safety and Health Act
PA	Preliminary Assessment
PCE	tetrachloroethene
PLC	Programmable Logic Controller
PPE	personal protective equipment
qPCR	quantitative polymerase chain reaction
QA/QC	quality assurance/quality control
QAPP	Quality Assurance Project Plan
RAB	Restoration Advisory Board
RCRA	Resource Conservation and Recovery Act
RDO	Remedial Design Optimization
RFS	Revised Feasibility Study
ROD	Record of Decision
RSE	Removal Site Evaluation
RWQCB	Regional Water Quality Control Board
SDWA	Safe Drinking Water Act
SOW	Statement of Work
TCE	trichloroethene
trans-DCE	trans-1,2-dichloroethene
VC	vinyl chloride
VOC	volatile organic compounds

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EXECUTIVE SUMMARY

Chlorinated solvents remain the most common class of contaminants at hazardous waste in the United States in general, as well as for the Department of Defense specifically. Bioremediation has emerged as a promising technology for addressing chlorinated solvents with relatively low capital costs, minimal (or no) secondary waste streams, minimal hazard to workers and the environment, *in situ* contaminant destruction, low maintenance, and minimal site disturbance. However, not all contaminated sites have significant populations of the most important bacteria required for efficient biodegradation of these contaminants, namely, *Dehalococcoides spp*. In those cases, bioaugmentation (adding a concentrated culture of the desired bacteria to a site) is becoming widely used to address potential biological limitations to degradation. While this has been demonstrated to be effective on a small scale, no rigorous full-scale demonstrations have been performed to evaluate different strategies for achieving successful growth and distribution of *Dehalococcoides spp*. bacteria to achieve site cleanup goals.

OBJECTIVES OF THE DEMONSTRATION

The overall objective of this work is to compare the cost and performance of full-scale bioaugmentation of chlorinated solvent contaminated groundwater using passive and active bacterial distribution approaches. The technical objectives for this demonstration are as follows:

- Extend bioaugmentation cost-effectively to full scale
  - Demonstrate cost-effective bacterial distribution at scales of hundreds, rather than tens, of feet
  - Demonstrate induction of complete dechlorination at the same scale
- Demonstrate that a low-cost, passive approach to bioaugmentation will achieve large-scale bacterial distribution and induction of complete dechlorination
- Compare and contrast effectiveness of passive and active approaches of bacterial distribution

The relative pros and cons of active recirculation and passive inject-and-drift strategies for large-scale bioaugmentation of chlorinated solvents in groundwater were evaluated in a side-by-side comparison at the Seal Beach Naval Weapons Station (NAVWPNSTA) Seal Beach Site 70 in the City of Seal Beach, California. Three phases of activities were completed for each of the treatment cells, as follows:

- **Phase 1 – Pre-Demonstration Laboratory Investigations.** Bench-scale testing was performed to demonstrate that the bioaugmentation culture could overcome the high sulfate concentrations at the site. In addition, deoxyribonucleic acid (DNA) analysis of site groundwater samples and commercially available cultures, were used to identify "biomarkers" that provided the ability to differentiate between the injected cultures and any native *Dehalococcoides spp.* (*DHC*).
- **Phase 2 – Tracer Test, Baseline Sampling, and "Pre-conditioning."** Following treatment cell construction, a tracer test was conducted in each of the treatment cells to verify the groundwater hydraulics in the shallow aquifer. Baseline

sampling was then conducted to assess conditions, including contaminant and degradation product concentrations, redox parameters, biological activity indicators, and *DHC* concentrations. Following baseline sampling, electron donor was injected into each treatment cell to create strongly reducing conditions and remove sulfate prior to bioaugmentation.

- **Phase 3 – Bioaugmentation and Monitoring.** This third and final phase involved injecting the dechlorinating culture into each of the two treatment cells and performing groundwater monitoring to compare with results from Phase 2.

DEMONSTRATION RESULTS

Bench-scale testing showed that complete dechlorination of TCE to ethene could be achieved even in the presence of high concentrations of sulfate, as long as sulfate-reducing conditions prevailed. Two dechlorinating cultures in microcosms with initial sulfate of 1,650 mg/L were equally successful in dechlorinating 16 mg/L TCE and 6 mg/L *cis*-DCE completely to ethene in 112 days with complete sulfate removal. In microcosms with much higher initial sulfate (9,270 mg/L), one of the cultures succeeded in converting all of the TCE to VC (45 µM) and ethene (119 µM) in 112 days, while removing about 36 percent of the sulfate. While DNA analysis revealed low concentrations of native *DHC* at the site in a few locations, it was determined that not all of the known functional genes for dechlorination were present. Specifically, the *vcrA* gene was absent in site ground water. As this functional gene is present in commercially available dechlorination cultures, it was tentatively selected as an appropriate biomarker for the bioaugmented culture pending results of DNA analysis of groundwater samples following the pre-conditioning phase.

Tracer testing performed following well installation confirmed that travel times in the two treatment cells were sufficiently short to satisfy project objectives. Baseline groundwater sampling confirmed that initial conditions were mildly reducing, with very little conversion of TCE to cis-1,2-dichloroethene (cis-DCE). It was also noted that baseline TCE conditions were quite high in both treatment cells. In the active treatment cell, a high of 140,000 µg/L was observed in the downgradient part of the cell, though concentrations were generally more like 5,000 to 10,000 µg/L. In the passive cell, TCE concentrations typically ranged from 1,000 µg/L to 3,000 µg/L in the upgradient part of the cell, but were much higher (on the order of 50,000 to 60,000 µg/L) in the bottom part of the middle of the passive cell. In the downgradient monitoring wells, TCE concentrations were more 10,000 to 20,000 µg/L.

During pre-conditioning, electron donor was distributed throughout most of the passive cell, and throughout the upgradient portion of the active cell. Where electron donor was distributed, sulfate-reducing conditions were generally achieved, and in some locations, TCE transformation to cis-DCE was observed. However, almost no vinyl chloride was detected, and *DHC* detections were few and at very low concentrations. Most importantly for the DNA analysis of groundwater samples, no detections of the vcrA functional gene were observed, confirming its utility as a biomarker of the bioaugmentation culture.

Bioaugmentation of both treatment cells occurred in January 2009, with three passive cell injection wells receiving culture, and the two active cell injection and recirculation wells

receiving culture. Following bioaugmentation and during injection of one percent sodium lactate, considerable increases in numbers of *DHC* bacteria (ranging from > 10^6 gene copies/mL to > 10^9 gene copies/mL) and all three functional genes (*tceA*, *bvcA*, and *vcrA*) were observed in all wells in the upper portion of the active cell. However, electron donor distribution became less effective over time, and more frequent and higher concentration injections were required to maintain an adequate distribution and efficient *DHC* growth and dechlorination. Overall, conversion of TCE to ethene was proceeding effectively in the upgradient third to half of the active treatment cell, but was not observed at the monitoring well two-thirds of the way down the treatment cell axis.

In the passive treatment cell, the electron donor distribution appeared to improve over time using the original monthly injection frequency. During the post-bioaugmentation phase, TCE and DCE were mostly removed, with VC and ethene observed for the first time at injection wells PIW-2 and -3 within two weeks after inoculation in January 2009. As of October 2009, total CVOCs continue to remain low at all three injection wells. However, little to no dechlorination was observed in the upper portion of the passive cell during the post-bioaugmentation phase. While it was not conclusively demonstrated, it is speculated that inhibition of dechlorination due to the presence of other contaminants in this area might have been a factor, as chloroform concentrations as high as 1,500 µg/L and carbon tetrachloride as high as 15,000 µg/L were measured in this area. In contrast, complete reductive dechlorination of TCE to ethene was observed in the central and lower portion of the passive cell. In October 2009 biodegradation accounted for reduction of total CVOC concentrations by 72 to greater than 92 percent at central and downgradient monitoring wells compared to CVOC concentrations observed in November 2008. Ethene production was observed as high as 410 µg/L. During the post-bioaugmentation phase, *DHC* bacteria and functional gene (*tceA* and *vcrA*) numbers increased immediately (within 2 weeks of inoculation) at all three injection wells on the order to >10^6 gene copies/L, and subsequently increased to similar concentrations in the downgradient two-thirds of the cell. These concentrations were sustained through October 2009.

The growth of *DHC* was measured in each cell using DNA analysis of groundwater samples based on the total number cells at the end of the study compared to the number injected, as well as by tracking increases over time at monitoring wells. Growth was very similar in both cells, with about a two order of magnitude increase in cell numbers estimated in each. It was also observed that concentrations at injection wells were sustained above about 10^6 cells/L throughout the test, and concentrations at monitoring wells increased to concentrations approximately equal to the injection wells by the end of the test. As with the first measure of growth, the two bioaugmentation strategies appeared equally effective based on this analysis.

Comparing and contrasting the distribution of *DHC* by the two bioaugmentation strategies was the key objective of this demonstration. Based on previous studies of bacterial transport in general, and bioaugmentation specifically, groundwater velocity appeared to be one of only a few parameters than can be easily manipulated during bioremediation that might have a significant impact on transport of *DHC*. Relative distribution efficiency of passive vs. active transport was assessed by comparing travel time of injected DHC to travel of the conservative tracer (iodide) used in Phase 2 of the demonstration. The groundwater velocity in the active cell was 1 to 1.8 ft/day, and for the passive cell it was 0.22 to 0.44 ft/d, a difference of approximately a factor of 5. The tracer and *DHC* data indicated that bacterial transport was not significantly

retarded compared to groundwater flow in either the active or passive cells. In fact, arrival of *DHC* was faster than that of the conservative tracer in the majority of the passive cell monitoring wells. In the active cell, *DHC* transport velocity appeared to be approximately equal to that of the conservative tracer. These results demonstrate that *DHC* was transported more rapidly relative to groundwater flow under passive conditions than active recirculation. This is consistent with previous indications that retardation of *DHC* transport relative to a conservative tracer increases with groundwater velocity. The net result was that the passive distribution strategy provided effective distribution of *DHC* (along with complete dechlorination to ethene) over a larger portion of the treatment cell than was achieved with active recirculation.

COST ANALYSIS

Projected implementation costs for a "typical" application (not including the intensive monitoring required for a rigorous demonstration) of bioaugmentation at a 0.5-acre site using the active and passive approach were estimated based on the demonstration costs. Most of the costs are similar (e.g. start-up, general construction, monitoring, and performance assessment) because they are common to both active and passive approaches. However, the construction and O&M costs for the active approach are approximately three times as high as for the passive approach. The result is an estimated cost for the active approach of $2.5M, compared to $1.5M for the passive approach. The primary drivers for this cost increase are the significantly higher amount of lactate required, and the higher costs for construction and maintenance of recirculation systems. For a site like Seal Beach, the benefits of implementing an active recirculation approach do not appear to be justified by the increased costs.

It should be noted, however, that some sites have conditions that would lead to more significant benefits for recirculation systems. For sites with very high groundwater flow velocities, recirculation might be needed to manage residence time within the treatment zone to avoid potential off-site migration of partially chlorinated byproducts such as *cis*-DCE and VC. Such a site would also allow electron donor to be distributed over a much larger distance prior to being degraded than was possible at Seal Beach, which would also increase the benefit. On the other hand, sites with very low groundwater velocities might make a passive system impractical because very little distribution can be achieved without enhancing the hydraulic gradient. What this demonstration indicates is that for sites that are closer to the "average" in terms of groundwater velocity, passive bioaugmentation systems are likely to be more cost-effective than active systems.

1.0 INTRODUCTION

This report provides the cost and performance data for full-scale bioaugmentation systems designed to transform chlorinated ethenes to ethene in groundwater. In particular, this report demonstrates the relative pros and cons of active recirculation and passive inject-and-drift strategies as a side-by-side comparison between the two approaches for large-scale bioaugmentation of chlorinated solvents in groundwater at the Seal Beach Naval Weapons Station (NAVWPNSTA) Site 70 in the City of Seal Beach, California. This project is sponsored by the Environmental Security Technology Certification Program (ESTCP) Project CU-0513, with additional funds provided by Naval Facilities Engineering Command Southwest (NAVFAC SW). The principal investigator for this project is Mr. Joey Trotsky from Naval Facilities – Engineering Services Command (NAVFAC ESC), and the co-principal investigator is Dr. Kent Sorenson of Camp Dresser & McKee Inc. (CDM). CDM is a demonstration partner under contract number N68711-05-C-0063.

The two full-scale bioaugmentation strategies were evaluated in treatment cells in the same chlorinated solvent source area at Site 70. Three phases of activities were completed for each of the treatment cells, as follows:

- **Phase 1 – Pre-Demonstration Laboratory Investigations.** Bench-scale testing was performed to demonstrate that the bioaugmentation culture could overcome the high sulfate concentrations at the site. In addition, deoxyribonucleic acid (DNA) analysis of site groundwater samples and commercially available cultures, including quantitative polymerase chain reaction (qPCR), clone library development, and DNA sequencing were used to identify "biomarkers" that provided the ability to differentiate between the injected cultures and any existing *Dehalococcoides spp.* (*DHC*) that may have naturally existed in the groundwater.
- **Phase 2 – Tracer Test, Baseline Sampling, and "Pre-conditioning."** Following treatment cell construction, a tracer test was conducted in each of the treatment cells to verify the groundwater hydraulics in the shallow aquifer. Following the tracer test, baseline sampling was conducted to assess baseline conditions including contaminant and degradation product concentrations, redox parameters, biological activity indicators, and *DHC* concentrations. Following baseline sampling, electron donor was injected into each treatment cell to create strongly reducing conditions and remove sulfate prior to bioaugmentation.
- **Phase 3 – Bioaugmentation and Monitoring.** This third and final phase involved injecting the dechlorinating culture into each of the two treatment cells and performing groundwater monitoring to compare with results from Phase 2.

The remainder of Section 1 briefly discusses background information, demonstration objectives, and regulatory drivers. Section 2 contains a description of the technology to be demonstrated. The performance objectives are provided in Section 3, and Section 4 gives a site description. Section 5 outlines the test design and results, while Section 6 provides a detailed performance assessment. Section 7 uses the demonstration data to provide a cost assessment of the technology, and Section 8 outlines implementation issues.

1.1 BACKGROUND

Chlorinated solvents are the most common class of contaminants in groundwater at hazardous waste sites in the U.S. In 1993, the Agency for Toxic Substances and Disease Registry (ATSDR) compiled a list of the top 25 contaminants detected at hazardous waste sites on the National Priorities List (NPL). The ATSDR ranking identified 8 of the top 20 contaminants as chlorinated solvents and their intrinsic degradation products, including two of the top three (Pankow & Cherry, 1996). The ranking was updated by the ATSDR on their Internet site based on 1996 data with similar results. Of particular significance is the identification of trichloroethene (TCE) and tetrachloroethene (PCE) as the first and third most common contaminants at NPL sites in both surveys. Chlorinated solvents are also the most common contaminants at Department of Defense (DoD) sites. While NAVWPNSTA Site 70 is not on the NPL, it does have chlorinated solvent-contaminated groundwater.

While significant progress has been made in addressing solvent sites, parties responsible for cleaning up sites with chlorinated solvents in groundwater are faced with several technologies with significant capital costs, secondary waste streams, the involvement of hazardous materials, and the potential for additional worker or environmental exposure. A more ideal technology would involve lower capital costs, would not generate secondary waste streams, would be non-hazardous to workers and the environment, would destroy contaminants *in situ*, would be low maintenance, and would minimize disturbance of the site.

Bioremediation has been identified as one of the major technologies that may be able to address this problem at chlorinated solvent sites. However, bacteria capable of complete dechlorination of chloroethenes to ethene are not always present at these sites, which can cause dechlorination to "stall" at *cis*-1,2-dichoroethene (cis-DCE). When this occurs, one mitigation strategy is to perform bioaugmentation, which is the introduction of bacteria capable of complete dechlorination to ethene into the affected groundwater. This process has only been successfully demonstrated at the pilot scale, however, and many issues related to full-scale implementation with important cost implications still need to be addressed.

Previous bioaugmentation pilot studies were conducted on the scale of tens of feet and used active recirculation for distribution of the bioaugmentation culture. The current demonstration will complement and build on pilot testing already completed by NAVFAC SW at NAVWPNSTA Seal Beach, Site 40 that successfully uses a low-cost, passive approach for implementation of bioaugmentation. The purpose of this demonstration is to compare the low-cost, passive method for implementation of bioaugmentation to the active recirculation method for full-scale application at a scale of hundreds of feet or more.

1.2 OBJECTIVE OF THE DEMONSTRATION

The overall objective of this work is to compare the cost and performance of full-scale bioaugmentation of chlorinated solvent contaminated groundwater using passive and active distribution approaches. The technical objectives for this demonstration are as follows:

- Extend bioaugmentation cost-effectively to full scale

  - Demonstrate cost-effective bacterial distribution at a scale of greater than one hundred feet, rather than tens of feet as has previously been demonstrated
  - Demonstrate induction of complete dechlorination at the same scale
- Demonstrate that a low-cost, passive approach to bioaugmentation will achieve large-scale bacterial distribution and induction of complete dechlorination
- Compare and contrast effectiveness of passive and active approaches of bacterial distribution

Specific performance objectives for each test scenario are provided in Section 3.

1.3 REGULATORY DRIVERS

The presence of chlorinated solvents including PCE, TCE, *cis*-DCE, *trans*-1,2-dichloroethene (*trans*-DCE), and vinyl chloride (VC) in groundwater is one of the most persistent environmental problems at NPL sites, as discussed in Section 1.1. The Safe Drinking Water Act (SDWA) maximum contaminant levels (MCLs) for these compounds are very low, as shown in Table 1-1, which makes cleanup of these sites difficult given that solubilities can be six orders of magnitude above the MCL.

Table 1-1. Regulatory Limits for Chlorinated Compounds

Compound	Regulatory Limit (MCL)[1] mg/L	Solubility @ 25°C mg/L
Tetrachloroethene	0.005	150[2]
Trichloroethene	0.005	1,100[2]
cis-1,2-dichloroethene	0.07	3,500[3]
trans-1,2-dichloroethene	0.1	6,300[2]
Vinyl chloride	0.002	2,763[4]

[1] 40 CFR 141.61
[2] Knox et al., 1993
[3] Howard, 1990
[4] Howard, 1989

2.0 TECHNOLOGY

The first publications describing field-scale bioaugmentation using *DHC* bacteria to treat chlorinated ethenes appeared in about 2000, so this is still a relatively new technology for full-scale field applications. This section provides a description of the underlying theory that is fundamental for technology application, an overview of the history of the development of the technology, and a brief comparison of the advantages and limitations of bioaugmentation relative to other source remediation technologies.

In general, bioaugmentation for remediation of chlorinated solvents involves addition of electron donor (biostimulation) and a bacterial culture that contains *DHC*. Different techniques are available for bioaugmentation of groundwater, and the appropriate technique depends not only on the relevant application (i.e., plume containment vs. source treatment), but also on the electron donor selected. Because all bioaugmentation methods require the addition of electron donor, it is important to consider the electron donor delivery method when selecting a bioaugmentation approach. Several electron donor emplacement methodologies have been used for biostimulation, including (adapted from Interstate Technology Regulatory Council (ITRC) [2005]):

- Conventional injection wells - one or a network of wells is usually used with large volume, liquid electron donor injections; most applicable for moderate to high permeability conditions
- Direct-push injection points - a network of more closely spaced points is usually used with small volume, liquid electron donor injections; most applicable for relatively homogeneous, moderate to high permeability conditions with low to medium advection to dispersion ratios
- Trenching – passive trenches are usually backfilled with a large mass of solid electron donor (e.g., mulch or chitin) and/or a long-lived liquid electron donor, often mixed with sand; can be used in all permeability conditions as long as the permeability of the trench is at least as high as the formation
- Hydraulic or pneumatic fracturing – either solid or liquid electron donors are emplaced during or immediately after fracturing; generally used in low permeability conditions or highly heterogeneous conditions in which low permeability zones require treatment

The current demonstration focuses on implementing both passive and active approaches for bioaugmentation, both of which use conventional injection wells.

2.1 TECHNOLOGY DESCRIPTION

This description of the fundamentals required for application of the technology provides an overview of bioaugmentation for chlorinated solvent contaminated groundwater. First, a discussion of the basics of chlorinated ethene degradation is provided. Second, issues related to scale-up of bioaugmentation are presented. Finally, factors that can affect bacterial transport in the subsurface are discussed.

2.1.1 Chlorinated Ethene Degradation

Complete biological reductive dechlorination of PCE and TCE to ethene was first documented only 2 decades ago (Freedman and Gossett, 1989), and the pathway was observed to proceed as follows: PCE → TCE → DCE → VC → ethene. It has since been well documented (DiStefano et al., 1991; deBruin et al., 1992; DiStefano et al., 1992; Ballapragada et al., 1997; Fennell et al., 1997; Carr and Hughes, 1998) and is being used successfully to treat chlorinated ethenes in groundwater (e.g., Song et al., 2002). Complete reductive dechlorination generally has two requirements. First, redox conditions must be sufficiently reducing that reductive dechlorination of DCE and VC to ethene is thermodynamically favorable. The free energy yielded by redox reactions varies substantially depending upon the electron acceptor. During respiration, microorganisms will preferentially use the electron acceptors yielding the greatest free energy (e.g., Bouwer, 1994). The order of preference for the most common inorganic electron acceptors is oxygen, nitrate, manganese (IV), iron (III), sulfate, and carbon dioxide (Bouwer, 1994; Cord-Ruwisch et al., 1988). Therefore, the dominant microbial community in a groundwater system is largely dependent upon the distribution of electron acceptors. While PCE and TCE reduction might occur under iron-reducing conditions, reduction of DCE and VC to ethene generally requires at least sulfate reducing conditions, or more preferably methanogenic conditions (Semprini et al., 1995; Sorenson, 2000; NAVFAC, 2003, http://www.ert2.org/dce/tool.aspx). When electron donor is limited, conditions will often not be sufficiently reducing to achieve complete dechlorination, causing it to "stall" at DCE. This can be overcome simply through the addition of a compound that acts as an electron donor, often consisting of a fermentable carbon source (Sorenson, 2003).

The second requirement for complete reductive dechlorination is a biological community capable of carrying out the reaction. It is widely accepted that bacteria capable of anaerobic reductive dechlorination are vital to biological dehalogenation processes in anoxic environments (Smidt et al., 2000). In fact, an increasing body of evidence suggests that complete biological reductive dechlorination of PCE and TCE to ethene requires the presence of a strain of the bacterium *DHC* (Cupples et al., 2003; He et al., 2003; Hendrickson et al., 2002). Recent advances in molecular techniques now allow scientists to characterize microbial communities, including identification of dechlorinators, more fully. This has lead to the discovery of many organisms capable of dechlorinating various compounds (Holliger et al., 1999). Many of these organisms are capable of reducing PCE and TCE to DCE (Holliger et al., 1999; Drzyzga and Gottschalk, 2002), but only *DHC* have been found to be capable of complete dechlorination of PCE and TCE to ethene in a pure culture (Maymó-Gatell et al., 1997; Maymó-Gatell et al.,1999; Maymó-Gatell and Zinder, 2001). A different strain, *DHC* strain FL2, has been implicated for complete dechlorination in a mixed culture, but it has not been isolated to date (Löffler et al., 2000). Of particular importance is that a recent study of 24 field sites in North America and Europe found that strains of this organism were present at all 21 sites that exhibited complete dechlorination to ethene, while none were found at the three sites examined where dechlorination stopped at *cis*-DCE (Hendrickson et al., 2002). This suggests that while *DHC* are relatively common and widely distributed, their absence at a site might prevent complete dechlorination. It should be noted that detection of the *DHC* genus does not necessarily mean that complete dechlorination of PCE or TCE will occur at a site because some strains are not capable of dechlorinating PCE and TCE. For example, strain CBDB1 grows by the dechlorination of chlorinated benzenes and

possibly dioxins, but cannot grow by dechlorination of PCE or TCE (Adrian et al., 2000; Bunge et al., 2003).

2.1.2 Bioaugmentation Scale-Up Issues

Bioaugmentation, the *in situ* addition of an exogenous bacterial culture containing *DHC* (in this case) to site groundwater, is gaining acceptance as a viable strategy for remediation of chlorinated solvents in groundwater, especially when these bacteria are not naturally present at a site and reductive dechlorination is found to "stall" at *cis*-DCE. Several laboratory cultures containing *DHC,* e.g., *Dehalococcoides ethenogenes* strain 195, have been shown to be capable of complete dechlorination of PCE, TCE, and DCE to ethene (Fennell et al., 2001; Maymó-Gatell et al., 1999; Maymó-Gatell et al., 1997; Richardson et al., 2002). In addition, several studies have demonstrated that bioaugmentation using *DHC*-containing mixed cultures can overcome DCE stall and facilitate complete dechlorination at the field pilot scale (Ellis et al., 2000; Lendvay et al., 2003; Major et al., 2002).

While these results are very promising, the transport scale of this work has been no greater than 30 feet. To receive regulatory and DoD end user acceptance, cost-effective approaches for growing large volumes of *DHC*-containing cultures and distributing them across a scale of hundreds of feet or more need to be demonstrated and validated. In particular, distribution of bacteria on a large scale presents a challenge both from a subsurface transport and from a cost standpoint. The distribution of introduced cultures during bioaugmentation is generally quite limited initially both because of the adhesion of bacteria to the soil matrix and the filtering effect of soil to particles such as bacteria. Although low-adhesion strains of bacteria have been developed for bioaugmentation in some applications (Steffan et al., 1999), this is only possible with pure cultures. Because *Dehalococcoides ethenogenes* is only grown in mixed culture for bioaugmentation, its adhesion has not been manipulated.

Filtration theory has been used to model bacterial transport during injection, and predicts that soil will be an efficient filter for bacteria, reducing concentrations by several orders of magnitude within the first meter of transport from the injection well and generally limiting transport to less than 2 meters (m) from the injection location, even in the absence of sorption (Goltz et al., 2001; Martin et al., 1996). During pilot-scale demonstrations, *D. ethenogenes* has been further distributed after inoculation through forced advection (recirculation) systems (these are described in more detail in Section 2.2). While these systems have been effective at transporting bacteria approximately 10 feet in 5 weeks (Lendvay et al., 2003) or up to 30 feet in 3 months (Major et al., 2002), larger scale distribution has not been well documented. Furthermore, the use of such systems on a scale of hundreds of feet would either require many injection and extraction wells to achieve distribution on a similar time scale, or would require much higher extraction rates. Thus, the cost of scale-up could be very high. At active sites, cost increases go beyond merely the scale because recirculation pipes must be installed across roads, railroad tracks, or utilities, all of which can be problematic. A further complication is that obtaining regulatory approval to extract and reinject contaminated groundwater remains challenging at many sites. In some cases treating the extracted water is required, which eliminates many of the benefits of bioremediation.

2.1.3 Factors Affecting Bacterial Transport

The many factors that affect bacterial transport in the subsurface are widely varied and complex. Some of the physiological factors that have been implicated as influencing bacterial transport include cell size and shape, motility, cell wall type, and adsorption characteristics (Becker et al., 2004; Camesano and Logan, 1998; Witt et al., 1999). For bioaugmentation, inoculation fluid characteristics such as ionic strength and cell concentration have been identified as playing a role (Camesano and Logan, 1998; Gross and Logan, 1995), as well as flow velocity (Becker et al., 2004; Camesano and Logan, 1998). Other researchers have suggested that the physical heterogeneity of the porous medium is a primary factor influencing bacterial attachment (Campbell Rehmann and Welty, 1999; Fontes et al., 1991; Ren et al., 2000). Finally, heterogeneity of the attachment characteristics within a particular bacterial population has also been implicated as affecting transport (Mailloux et al., 2003; Albinger et al., 1994; Glynn et al., 1998).

With all of these factors contributing to bacterial transport, development of a rigorous model that accurately accounts for any one of the factors, let alone the interactions of several factors, would be a lofty goal. Taking flow velocity as an example, some studies have found that attachment of motile bacteria to porous media increased more with decreased flow rates than nonmotile bacteria (Becker et al., 2004), while others have found that it increased less (Camesano and Logan, 1998). As different bacteria were used in the studies, it is likely that some of the other factors mentioned above also played a critical role, but that there are simply too many variables to design a comprehensive study that can elucidate their complex interactions. Becker et al. (2004) noted that some of their results for different flow rates were "perplexing;" that is, flow rate affects transport behavior in ways that are not well understood. To complicate matters further, it has been noted that laboratory studies of bacterial transport have not successfully predicted field-scale transport (Harvey et al., 1993).

Although the complexity of bacterial transport and the development of a general, predictive model that can be used to design bioaugmentation strategies for a wider range of bacteria is daunting, such a general understanding is not required in the specific case of optimizing strategies for bioaugmentation using *DHC*-containing cultures for chlorinated solvent remediation. Given that the focus is on only one population of bacteria, the physiological factors that affect transport are no longer variable, and an empirical approach can be used to evaluate the remaining factors. An empirical approach is further justified by the difficulty noted above in accurately representing field-scale transport phenomena at the laboratory scale. Ignoring the physiological factors, the transport factors remaining that can be controlled during bioaugmentation are reduced to flow velocity, ionic strength, and cell concentration. While low ionic strength solutions have been shown to improve bacterial transport (Gross and Logan, 1995; Fontes et al., 1991), the improvements are not always large, and the logistical difficulty of injecting large volumes of low ionic strength solutions at field scale in varied geologic conditions is problematic (Camesano and Logan, 1998). The degree to which bacterial dispersal can be achieved at high concentrations depends upon whether the cells exhibit "blocking" behavior or "ripening" behavior (Camesano and Logan, 1998). Blocking implies that the cells do not tend to stick to each other, so they block attachment sites, forcing other cells to flow beyond them. This behavior allows high cell concentrations to be used to enhance dispersal. Ripening implies that the cells adhere strongly to each other and tend to increase the filtering efficiency of the porous

medium, preventing distribution of cells at high concentrations. As it has already been demonstrated that injection of *DHC* at relatively high concentrations (~10^8 cells/mL) can be used successfully to achieve distribution at a scale of tens of feet, ripening does not appear to be a problem. Thus, for a given site, flow velocity appears to be one of the most important factors affecting bacterial transport that can easily be controlled during full-scale implementation.

While the fundamental issues affecting transport of *DHC* (or bacteria in general) are not well understood, results from a recent study at NAVWPNSTA Site 40 (see Section 2.2) suggest that a passive distribution system (low velocity) may be far more cost-effective for scale-up than an active recirculation system (high velocity). This study is designed to validate these results by measuring *DHC* transport and the resulting induction of complete dechlorination using both passive and active distribution approaches at full scale. The empirical approach described herein will provide information regarding a potential key control on bacterial transport at full scale, avoiding the concern of representativeness of laboratory-scale studies. It will also provide this information in a timely manner so that the results can be applied to current problems quickly, which would be very unlikely if a fundamental research approach were used.

2.2 TECHNOLOGY DEVELOPMENT

The use of active recirculation to distribute bacteria and induce complete dechlorination is well documented at the pilot scale (Ellis et al., 2000; Lendvay et al., 2003; Major et al., 2002; Hood et al., 2008), although sufficient sampling was not performed in all cases in order to provide a full assessment of bacterial growth and distribution. For example, in the Ellis et al. study (2000) at Dover Air Force Base, *DHC* was not analyzed in field samples. For the Bachman Road Site study (Lendvay et al., 2003), *DHC* analysis was performed, but it was already present in the first post-inoculation samples 35 days after inoculation. A study at Kelly Air Force Base (Major et al., 2002) was the only one for which *DHC* transport times could be reasonably estimated and compared to conservative transport times. Based on bromide transport data and *DHC* detections provided in Major et al., travel times for *DHC* were between 61 and 176 times longer than conservative transport. Based on the fact that VC was detected 15 days after inoculation, the Bachman Road Site study suggested that *DHC* transport time along the short flow path from the injection/inoculation wells (approximately 3.2 meters) was only about 2.3 times greater than conservative transport times based on the reported Darcy velocity for the test area (Lendvay et al., 2003). The Cape Canaveral LC-34 project (Hood et al., 2008) had *DHC* bacteria already present in the treatment cell prior to bioaugmentation; however, post-bioaugmentation operations showed a 2-3 orders of magnitude increase in cell counts, as well as significant production of ethene. Still, quantification of transport of the added *DHC* bacteria could not be performed.

While these studies were conducted on small scales, other studies looked at bioaugmentation using active recirculation at a larger scale. Scheutz et al., 2008 used active recirculation for bioaugmentation at a larger scale (approximately 100 feet between injection and extraction wells). This field demonstration showed distribution of electron donor more than 65 feet from injection wells, as well as induction of dechlorination to ethene at a similar scale. However, it was determined that indigenous bacteria were capable of performing dechlorination to ethene, and that the *vcrA* gene that encodes for VC reductase was present during baseline sampling. Bioaugmentation was performed to reduce lag times for complete dechlorination; however, quantification of transport of introduced bacteria could not be performed.

In contrast to these recirculation systems, passive *DHC* distribution approach was recently demonstrated in a bioaugmentation pilot test at NAVWPNSTA Seal Beach, Site 40. Prior to the bioaugmentation phase at Site 40, biostimulation was performed for 8 months to overcome the electron donor limitation at the site, which initially had sulfate concentrations of 200 to 500 milligrams per liter (mg/L) (Figure 2-1). As predicted based on thermodynamics and field observations (Bouwer, 1994; Semprini et al., 1995; Sorenson, 2000; NAVFAC, 2003), dechlorination of PCE to DCE occurred shortly after the onset of sulfate reduction and the removal of sulfate within about 2 to 3 months after the start of biostimulation (French et al., 2003; Rahm et al., 2006). Although conditions became methanogenic and electron donor was abundant for over 6 months, dechlorination beyond *cis*-DCE did not occur after more than a year (Figure 2-2(a)). Highly sensitive DNA analysis performed after biostimulation revealed that no *DHC* were present at the site (Rahm et al., 2006).

In April 2003, two wells (MW-40-22 and MW-40-25, see Figure 2-3), were inoculated with 20 liters (L) each of a commercially available *DHC*-containing culture. Forced advection occurred only during brief periods when sodium lactate was periodically injected in MW-40-28, approximately 8 feet from the two inoculation wells (Figure 2-3). No other injection or extraction was performed during the test. During injection, the average hydraulic gradient in the treatment cell was 0.004, while it was approximately 0.00024 under ambient conditions. Based on these conditions, the injection durations, an average hydraulic conductivity of 97 feet per day (ft/d), and an estimated effective porosity of 0.20, the expected travel times for groundwater to move from inoculation well MW-40-22 to downgradient monitoring wells MW-40-23 (7.2 feet) and MW-40-24 (16.5 feet) are 26 days and 93 days, respectively (Table 2-1). In MW-40-23, *DHC* were detected using qPCR in the first post-inoculation samples analyzed from that well, some 91 days after inoculation (Figure 2-4) (see also Rahm et al., 2006). Thus, the maximum travel time for *DHC* was about 3.5 times longer than that expected for conservative transport with groundwater. The detection of VC at this location in the June 18 sample (Table 2-2), however, suggests that *DHC* activity may have been present much earlier, just 63 days after inoculation. In that case the travel for *DHC* would be only 2.4 times longer than conservative transport.

Similar to MW-40-23, *DHC* were detected in the first post-inoculation samples analyzed from MW-40-24, in this case 119 days after inoculation (Figure 2-4 and Table 2-1). VC was actually not detected at this location until the next sampling round (Table 2-2), so 119 days is likely close to the actual arrival of *DHC* at this well. The travel time for *DHC* was therefore only about 1.3 times longer than would be expected for conservative transport. Therefore, although groundwater velocities were fairly slow (0.12 ft/d without injection) in this passive system, transport of *DHC* was only slightly retarded. In addition, no lag time was observed for dechlorination activity after inoculation. VC and ethene were both observed for the first time in the inoculation wells about 1 week after inoculation (which might have been facilitated by the strongly reducing conditions already present). As noted above, VC was also detected in downgradient monitoring wells within a few weeks of the estimated arrival time of *DHC*.

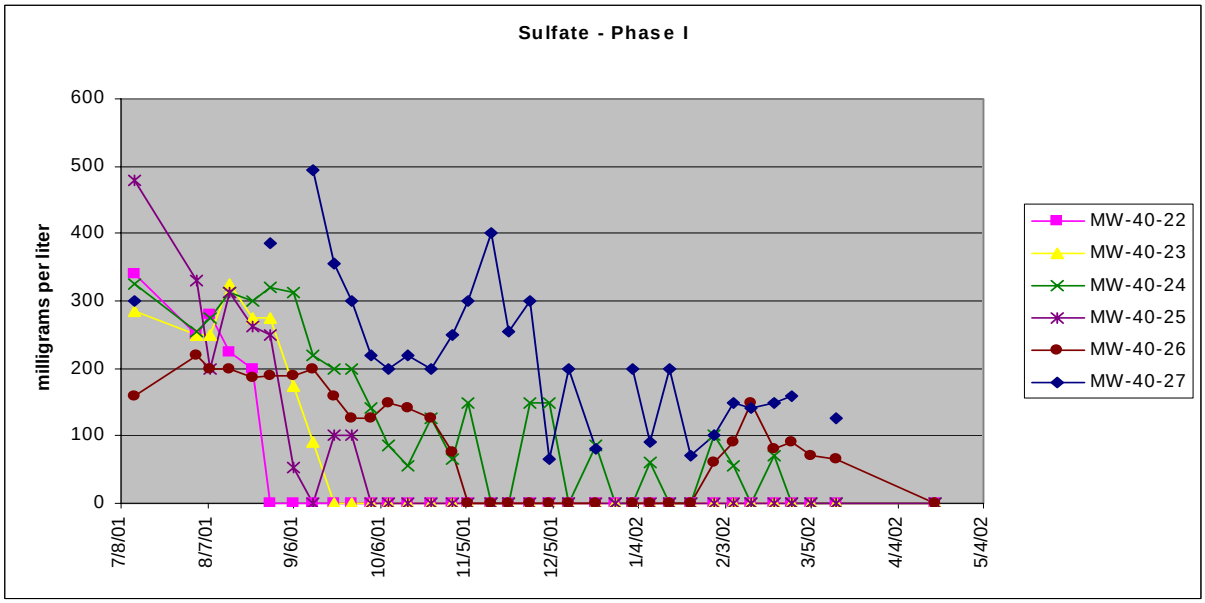

Figure 2-1. Sulfate removal at Seal Beach Site 40 wells following the start of lactate injections during biostimulation.

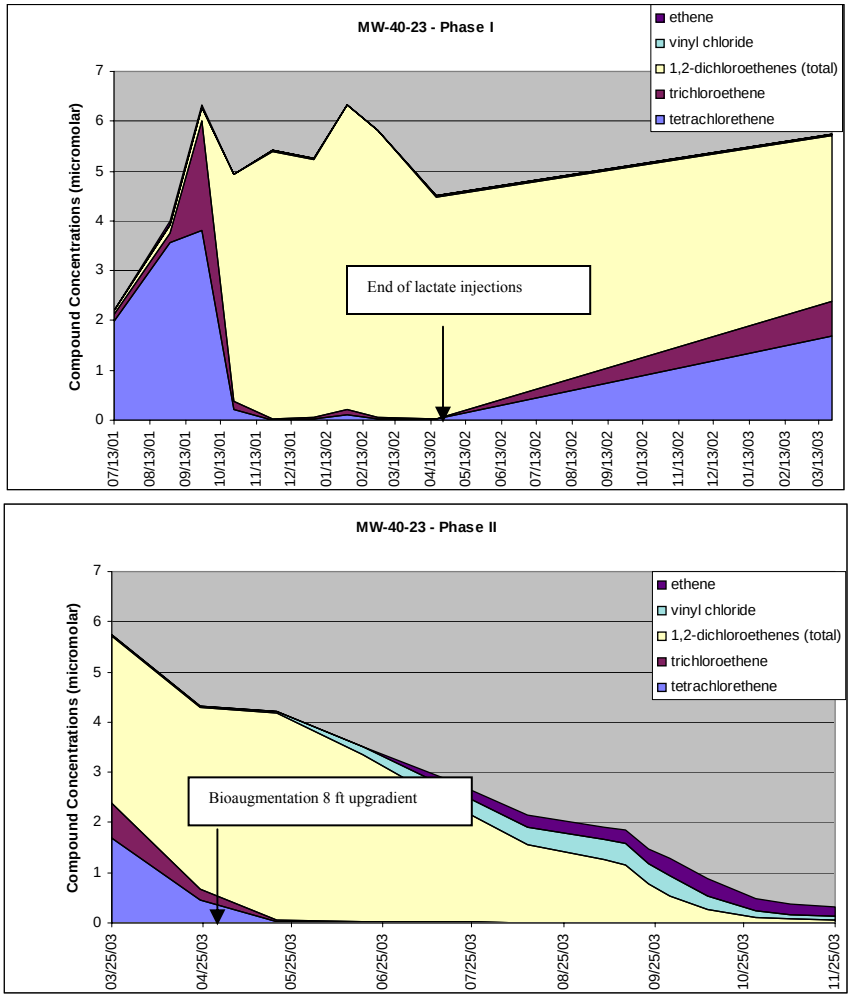

Figure 2-2. Typical dechlorination results during biostimulation at Seal Beach Site 40 including stoichiometric conversion of PCE to cis-1,2-DCE without any production of vinyl chloride or ethene, and with some rebound of PCE and TCE in the absence of lactate injections (a). Typical dechlorination results following bioaugmentation including disappearance of cis-1,2-DCE concomitant with the appearance of vinyl chloride and ethene; chloroethenes near or below MCLs after 8 months (b).

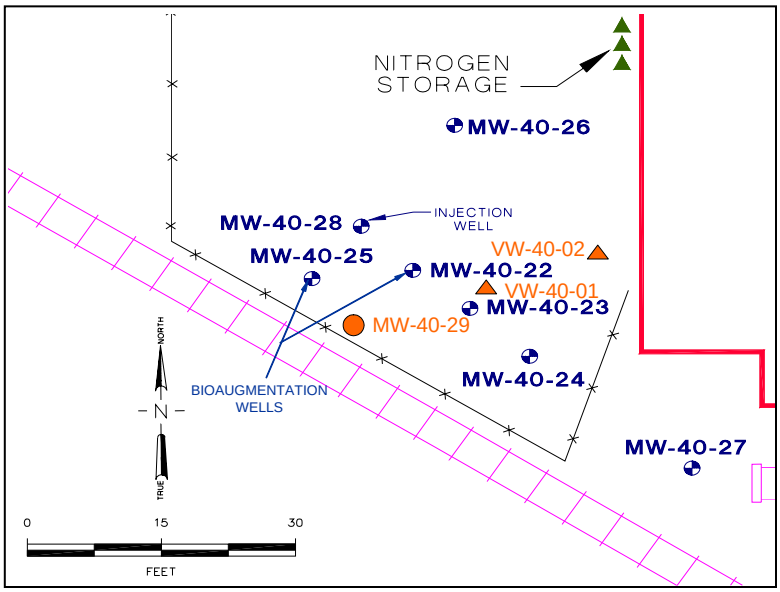

Figure 2-3. Site plan for pilot test at Seal Beach Site 40.

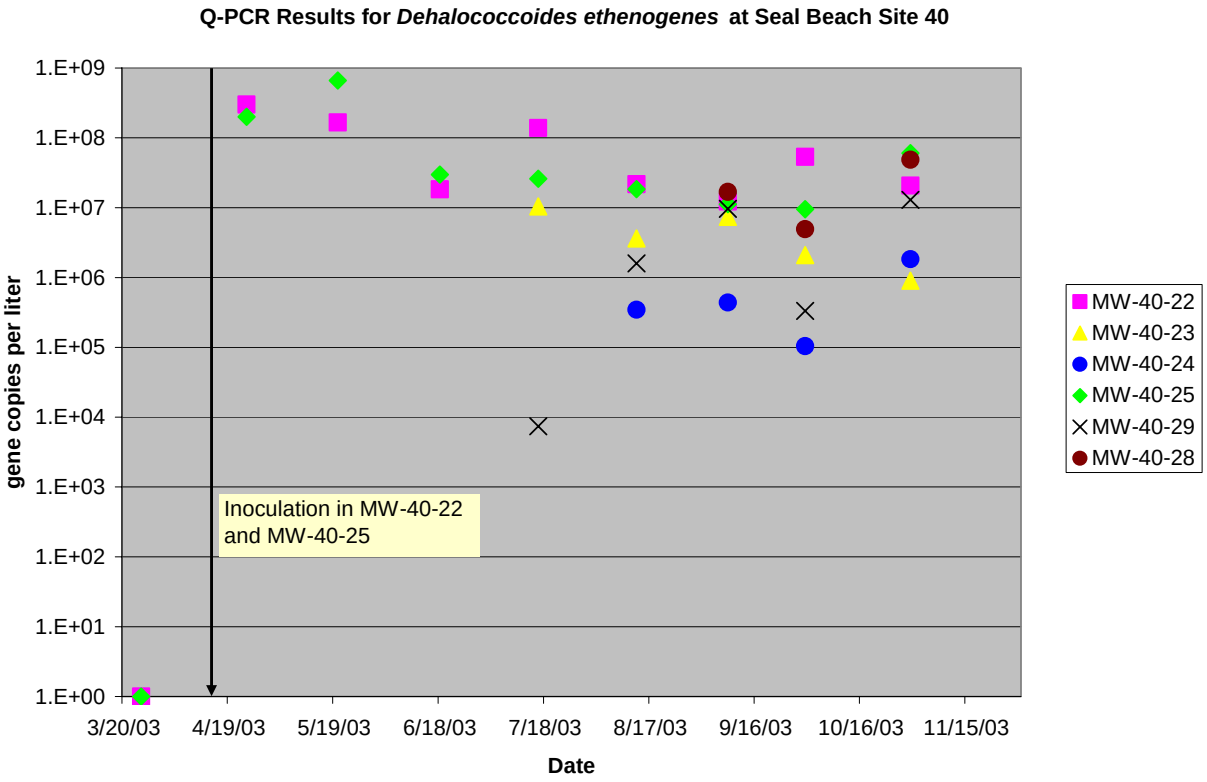

Figure 2-4. Q-PCR results for *D. ethenogenes* at Seal Beach Site 40 showing passive transport of the bacteria more than 16 ft downgradient (MW-40-24) and 8 ft upgradient (MW-40-28) in a few months.

Table 2-1. Estimated Retardation Factors for *DHC* Transport for Kelly Air Force Base Recirculation System (estimated from Major et al. (2002) and the NAVWPNSTA Site 40 passive system)

	Kelly Air Force Base		NAVWPNSTA Site 40	
Well	**B1**	**E1**	**MW-40-23**	**MW-40-24**
Distance from inoculation point (ft)	7.9	30	7.2	16.5
Estimated conservative travel time (d)	0.17	1.2	26	93
Estimated *D. ethenogenes* travel time (d)	$17 < t < 30$	$72 < t < 93$	$63 < t < 91$	119
Retardation factor	$100 < R < 176$	$61 < R < 79$	$2.4 < R < 3.5$	1.3

Table 2-2. Chloroethene and Ethene Concentrations (μg/L) for Bioaugmentation Pilot Test at NAVWPNSTA Site 40 (initial VC and ethene were < 2 μg/L at all wells and ethene arrived with VC in all wells).

Well	Max DCE	Final DCE	Max VC	Final VC	First VC	Max Ethene
MW-40-22	310	4	45	2.7	April 24	5
MW-40-25	390	4	62	2	April 24	8
MW-40-23	400	6	26	4.8	June 18	9
MW-40-29	410	16	30	8.3	June 18	6
MW-40-24	410	35	63	31	August 14	21

The introduced *DHC* were observed not only 16 feet downgradient from the inoculation point, but also 8 feet upgradient in the lactate injection well, in less than 4 months (Figures 2-3 and 2-4) (see also Rahm et al., 2006). Just as important, the arrival of *DHC* corresponded closely to the first appearance of VC and ethene in each of the monitoring wells (Table 2-2). Furthermore, concentrations of PCE, *cis*-DCE, and VC were all near or below MCLs throughout the treatment area in less than 8 months (Figure 2-2(b), Table 2-2). While aqueous and soil gas concentrations of degradation products only accounted for approximately 50 percent of the mass of *cis*-DCE degraded (data not shown), many months of biostimulation data with far larger electron donor injections demonstrated that dilution or displacement did not play a significant role in *cis*-DCE's disappearance (Figure 2-2(a)).

Table 2-1 summarizes the bacterial transport that was observed at both the Kelly Air Force Base study and NAVWPNSTA Site 40. From Table 2-1, the Kelly Air Force Base travel times suggest far greater retardation of *DHC* than was observed at Site 40. As the same culture was used in both cases, the reason for this disparity is not clear. One significant difference was the electron donor solution used. At Kelly Air Force Base, the solution consisted of a combination of a time-weighted average of 3.6 mM methanol (approximately 115 mg/L) and 3.6 mM acetate (and approximately 212 mg/L). At NAVWPNSTA Site 40, a 3 percent solution of sodium lactate was injected weekly for 5 weeks, then the frequency was decreased to less than monthly. Groundwater was methanogenic in both studies prior to bioaugmentation, so redox conditions do not appear to be a factor in the transport differences observed. Another significant difference was the use of a recirculation system at Kelly Air Force Base compared to the passive system at NAVWPNSTA Site 40. In the case of motile bacteria, at least one study has shown that they were actually transported more effectively under low flow or no flow conditions than under forced advection conditions (Camesano and Logan, 1998). While it is not known whether flow

conditions are an important factor for distribution of *DHC,* which are non-motile, this possibility cannot be dismissed. As discussed above, flow conditions are the primary factor affecting transport of a given bacterium in the field that we can easily control. It is interesting that *DHC* were detected under passive conditions at NAVWPNSTA Site 40 not only downgradient, but also in MW-40-28, 8.1 feet upgradient of the inoculation well. This seems remarkable given that this transport occurred without any injections in the inoculation well to facilitate it.

The lag time prior to onset of dechlorination was insignificant in Lendvay et al. (2003), as was true at NAVWPNSTA Site 40. This raises the question of whether transport of *DHC* might be related to its growth. The two studies that had insignificant dechlorination lag periods (and presumably more rapid growth) showed *DHC* transport that was only mildly retarded relative to conservative transport, while the Kelly Air Force Base study had a significant lag period and exhibited greatly retarded transport of *DHC*. Prior to this demonstration, any potential connection between growth and transport or flow conditions and transport would have been speculative, but this demonstration directly measured the latter at full scale. In any case, the passive distribution system was not only highly successful for destroying *cis*-DCE at the pilot scale at Site 40, but also appeared to be equal or superior to more expensive and logistically challenging recirculation systems for distributing *DHC* throughout the area of interest (Table 2-2).

The second issue for which preliminary data have been collected at NAVWPNSTA, Site 40 is the potential ease with which the *in situ* dechlorinating community can be transferred from one location to another after growth and adaptation under site conditions. The bioaugmentation pilot test was completed in the fall of 2003. In June 2004, in order to demonstrate the proof of principle for the concept of redistributing the *in situ DHC*-containing community from the bioaugmentation area to new areas on-site, groundwater from MW-40-22 in the pilot area (Figure 2-3) was pumped into a tank and reinjected into MW-40-27, located downgradient. Sodium lactate had been injected into MW-40-27 in April 2004 to create conditions that would facilitate rapid growth of the dechlorinating populations. This exercise also served to help ensure the sustenance of the dechlorinating populations, which were being transferred from an area where chlorinated compounds were depleted to an area where PCE concentrations were above 800 micrograms per liter (µg/L).

Figures 2-5 and 2-6 reveal the results of this "proof of principle." Figure 2-5 shows the chemical oxygen demand (COD) increasing in response to the April lactate injections. It also shows the increase in the number of gene copies per liter of groundwater measured in the well following transfer of groundwater from the pilot test area.

It is particularly interesting to note the *DHC* DNA concentrations were actually an order of magnitude higher in MW-40-27 in July 2004 than they were in MW-40-22 (the well from which groundwater containing large amounts of *DHC* DNA was transferred). This indicates that *DHC* were actively growing to large numbers in MW-40-27 within 1 month. This point is further demonstrated by the data shown in Figure 2-6. While a small increase in DCE was observed prior to injection of water from the bioaugmentation area, PCE concentrations also increased slightly.

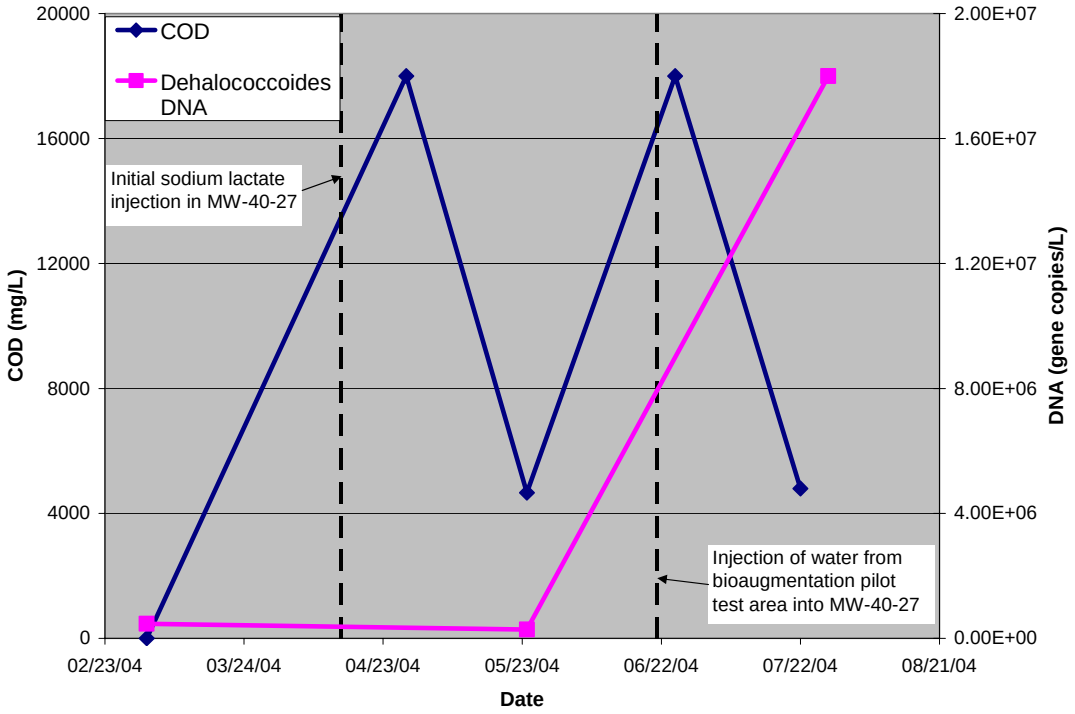

Figure 2-5. COD concentrations in well MW-40-27 at Seal Beach in response to lactate injections, and *Dehalococcoides* DNA concentrations in response to transferring groundwater from the bioaugmentation pilot test area.

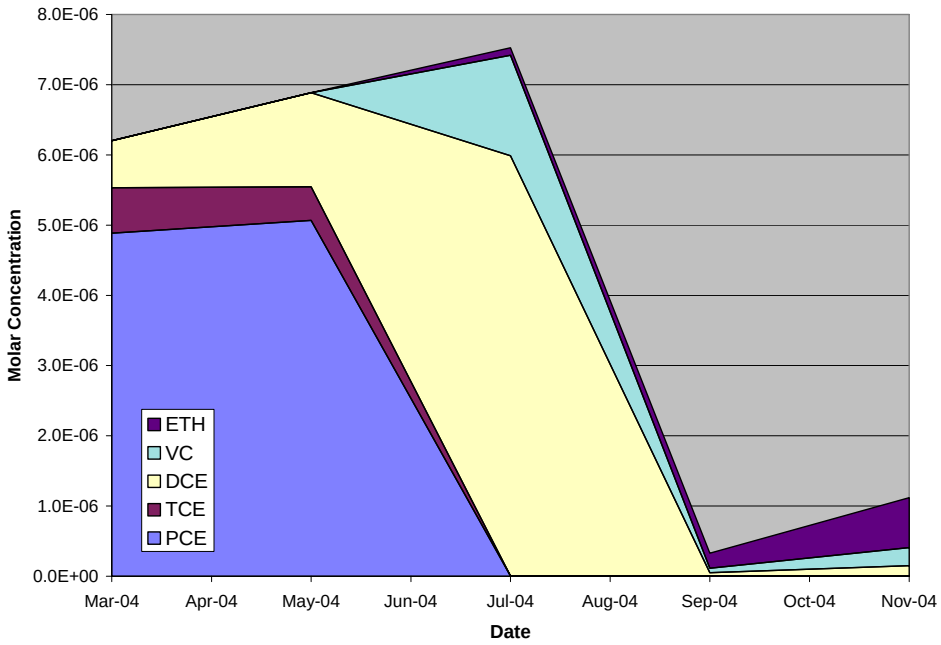

Figure 2-6. Dechlorination at well MW-40-27 following injection of water from MW-40-22. Note that initial PCE concentrations were 810 ug/L, TCE was at 85 ug/L, and DCE was 65 ug/L.

Within 1 month of the injection of MW-40-22 water in MW-40-27, however, PCE and TCE both were undetectable, VC and ethene were detected at significant levels for the first time, and the degradation products more than accounted for the mass of PCE that was degraded. These data demonstrate that once a robust, dechlorinating community is established *in situ*, it can easily be transported around a site to facilitate semi-passive distribution at a large scale without the need to purchase large volumes of culture or construct large-scale recirculation systems. The same thing could potentially be accomplished either by waiting long periods of time for transport of the bacteria with the natural gradient, or by installing a groundwater recirculation system, both of which have been done, but this approach appears to be much more cost-effective. This is an important consideration allowing for the potential use of a passive bacterial growth and distribution strategy.

2.3 ADVANTAGES AND LIMITATIONS OF THE TECHNOLOGY

Significant advantages of bioaugmentation technology in general include low risk to human health and the environment during implementation, low secondary waste generation, minimal impacts during operations, and overall risk reduction. In addition, when applied in a source area, bioaugmentation offers the potential for complete source cleanup using one technology without a requirement for separate polishing technologies, which is a significant advantage from a cost standpoint. Source removal technologies generally do not remove all of the chlorinated solvent present, and rely on polishing technologies including *in situ* bioremediation and monitored natural attenuation to achieve cleanup standards. *In situ* bioremediation with bioaugmentation integrates source removal and polishing, thereby facilitating attainment of cleanup goals by reducing the need for further infrastructure, treatability studies, modification of site conditions, etc. that may be required to implement a polishing technology following source removal.

Challenges for bioaugmentation can include any of the site-specific characteristics that limit application of many remedial technologies, including complex lithology, low permeability media, and high concentrations of competing electrons acceptors. In addition, this technology is probably not applicable for sites contaminated by large volumes of free-phase dense, non-aqueous phase liquid (DNAPL) (ITRC, 2005). Finally, the generation of methane is common at bioremediation/bioaugmentation sites, as is the temporary production of VC. Both of these can partition into the vadose zone above the water table, which can be a concern if the contamination is present in shallow groundwater underneath buildings or utility corridors.

Other technologies currently demonstrated at pilot or full-scale for chlorinated solvent remediation include thermal technologies (i.e., steam, electrical resistance heating or ERH, conductive heating), *in situ* chemical oxidation, surfactant/cosolvent floods, SVE/air sparging, and pump and treat. Steam injection and ERH both heat soil and water to volatilize chlorinated solvents for recovery, while *in situ* chemical oxidation destroys contaminants *in situ* using Fenton's reagent or other oxidants. Pumping and treating groundwater is currently used more for hydraulic containment, or to induce a gradient, than for chlorinated solvent remediation; however, this technology is frequently used as a baseline for comparison. Table 2-3 lists advantages and limitations of each.

Table 2-3. Advantages and Limitations of Competing Technologies

Technology	Advantages	Limitations
Bioremediation/ Bioaugmentation	All treatment performed in situ; low infrastructure and energy requirements; no secondary waste produced; costs moderate.	Relatively slower; requires longer monitoring period; not applicable for large volumes of free-phase DNAPL; production of methane and VC must be considered
Thermal (steam, ERH, conductive heating)	Relatively rapid source reduction possible; can be used for large volumes of free-phase DNAPL	Energy intensive, expensive; high secondary waste production
In situ chemical oxidation	Source reduction might be more rapid than bioremediation, though this is not well-documented; very little secondary waste produced.	Carbonates and organics compete for hydroxyl radical, oxidant is quickly consumed, limiting distribution in the subsurface; rebound of contaminants common; not applicable for large volumes of free-phase DNAPL
Surfactant/cosolvent flooding	Can be used for large volumes of free-phase DNAPL	Requires uniform, moderate to high permeability; high secondary waste production; only applicable for source areas; usually expensive and requires polishing
SVE/air sparging	SVE effective for vadose zone, short-term costs moderate.	Ineffective for source removal; air sparging requires intensive research at pilot scale; typically requires off-gas treatment at the surface
Pump and treat	Effective for hydraulic containment during remediation	Ineffective for source removal; difficult to terminate operations; expensive

In addition to the general advantages and limitations for bioaugmentation discussed above, each bioaugmentation approach being tested in this demonstration has its own advantages and limitations. For the active recirculation for bioaugmentation, the most significant advantage is that it provides the most control over amendment distribution because the gradients can be manipulated. Other advantages include:

- The ability to achieve fastest initial donor distribution, which can lead to more rapid onset of reducing conditions
- Can achieve larger distribution from an individual injection point (i.e. larger radius of influence during injection)
- Ability to add large amounts of amendments over a relatively short timeframe

The most significant disadvantage for active recirculation is that it generally has the highest capital costs and O&M requirements of any approach. Continual system monitoring, either by automated instrumentation, or by onsite staff, is needed to ensure upset conditions are not encountered and that all above ground equipment is operating as designed. In addition, logistical constraints at active facilities may impact placement of above ground infrastructure.

The primary advantage to passive approach for bioaugmentation is that it is a flexible approach that allows for frequent applications of electron donor, while keeping the operational requirements (and costs) low. Other advantages include:

- Ability to distribute and maintain high concentrations of electron donor to a large radius of influence from individual injection points
- Ability to perform frequent (i.e., monthly to quarterly) amendment injections cost effectively (on smaller scales)
- Large areas can be treated effectively with multiple injection points
- Minimal O&M and capital requirements compared to active recirculation.

The main disadvantage for the passive approach is because the primary distribution mechanism is ambient groundwater flow; the success of this injection technique is highly dependent on subsurface conditions at the site. If ambient groundwater is too slow, then the area treated using this approach may be limited. In addition, the time and number of injections required before reducing conditions are achieved can be significantly longer compared to an active recirculation system. Also, individual injections can take multiple days depending on subsurface conditions.

3.0 PERFORMANCE OBJECTIVES

This demonstration complemented work completed under the ESTCP project "Bioaugmentation for Chlorinated Solvent Remediation: Microbial Transport, Growth, Survival and Dechlorinating Activity" (ER-0315). It also built upon pilot testing completed by NAVFAC SW at NAVWPNSTA Site 40 that successfully used a low-cost, passive approach for implementation of bioaugmentation. As described in Section 1, the technical objectives for this project are as follows:

- Extend bioaugmentation cost-effectively to full scale
  - Demonstrate cost-effective bacterial distribution at scales of hundreds, rather than tens, of feet
  - Demonstrate induction of complete dechlorination at the same scale
- Demonstrate that a low-cost, passive approach to bioaugmentation will achieve large-scale bacterial distribution and induction of complete dechlorination
- Compare and contrast the effectiveness of passive and active approaches of bacterial distribution

The critical performance elements to measure were the results of the Phase 1 laboratory studies, the effects of the Phase 2 biostimulation/pre-conditioning, and the distribution of bacteria and extent of dechlorination in each of the treatment cells during Phase 3. Thus, the parameters to be monitored include DHC cell counts, chloroethenes and metabolites, electron donor and fermentation products, bioactivity and redox indicators, and cost. The performance criteria are identified specifically in Table 3-1. These performance objectives were derived from those that were presented in the ER-0513 Demonstration Plan.

3.1 PHASE 1 PERFORMANCE OBJECTIVES – BENCH SCALE TESTING AND BIOAUGMENTATION CULTURE SELECTION

Phase 1 of the ER-0513 project comprised conducting laboratory studies to confirm that dechlorination could be stimulated in the high sulfate environment present at NAVWPNSTA Site 70, and to select a bioaugmentation culture for the demonstration. These objectives are described further below.

3.1.1 Demonstration of Dechlorination using Site Groundwater

Site 70 was known to have sulfate and chloride concentrations in excess of 1,000 mg/L throughout the source area, with concentrations as high as 8,000 mg/L or more in some areas due to past chemical oxidation activities. Sulfate-reducing bacteria can compete with dechlorinators for available electron donor, and high sulfate concentrations have been shown to inhibit complete dechlorination when the sulfate cannot be removed. For this reason, ESTCP requested bench-scale testing be performed to evaluate a commercially available bioaugmentation culture for its ability to overcome the high sulfate concentrations and dechlorinate TCE to ethene.

Table 3-1. Technology Demonstration Performance Objectives

Project Phase	Performance Objective	Data Requirements	Success Criteria	Results
Quantitative Performance Objectives				
Phase 1: Demonstrate that selected bioaugmentation culture can overcome high sulfate conditions and perform dechlorination to ethene; select a bioaugmentation culture that contains *DHC* that can be distinguished from indigenous *DHC*	Demonstrate that at least one commercially available bioaugmentation culture can carry out complete dechlorination in the presence of high sulfate concentrations.	Electron donor, sulfate, chloroethene, and dissolved gas concentrations in bench-scale study	Production of ethene at concentrations at least 2X detection in bench study using site groundwater samples, reduction of 95% TCE	Successful – see Section 6.1.1
	Determine if *DHC* are present onsite; if so select a culture that contains a *DHC* strain or functional gene not present naturally at site.	qPCR results; DNA sequencing results	Identification of a biomarker that is present in bioaugmentation culture(s) but not in native strains of *DHC*	Successful – see Section 6.1.2
Phase 2: Determine baseline conditions and pre-condition treatment cells	Demonstrate that the layout and residence time of each treatment cell are such that demonstration performance can be meaningfully evaluated in a sufficient time.	Tracer compound (iodide) concentrations over time, groundwater velocity and direction, residence time	Construct treatment cells such that travel time from injection wells to monitoring wells is 6 months or less	Successful – see Section 6.2.1
	Demonstrate that electron donor can be adequately distributed to remove sulfate from the system and create strongly reducing conditions in both treatment cells.	Electron donor, sulfate, ferrous iron, and methane data to verify that whey injections have created strongly reducing conditions	Sulfate reducing conditions achieved at monitoring wells nearest to injection locations	Partially Successful – see Section 6.2.2
Phase 3: Determine full-scale effectiveness of bacterial distribution using passive and active circulation systems	Determine bacterial growth and distribution throughout the treatment cells using both bioaugmentation scenarios.	qPCR analysis, iodide tracer	Collect data that allow for quantitative assessment of tracer and bacterial transport time, and growth of bacteria over time	Successful – see Section 6.3.1
	Determine extent of dechlorination in both treatment cells during the test period	Chloroethene and dissolved gas concentrations; stable carbon isotope analysis	Achieve full dechlorination to ethene using both approaches – detection of ethene at greater than 2x detection limit at greater than or equal to 2/3 of the monitoring wells in a given treatment cell	Partially successful – see Section 6.3.2
Qualitative Performance Objectives				
	Determine ease of use for both active and passive approaches	Feedback from field personnel; injection and operational logs	Quantify operational requirements for each approach	Successful – see Section 6.4

The microcosm tests were conducted using site groundwater. Two mixed cultures of *DHC* that were most likely to tolerate high concentrations of sulfate and chloride were used in these tests. Whey was used as the electron donor, and live microcosms received trace nutrient amendments (e.g., NH4, PO4, yeast extract, and vitamin B12). The test for each well consisted of three microcosm bottles: 1) killed control; 2) whey, trace amendments, and bioaugmentation culture #1; and 3) whey, trace amendments, and bioaugmentation culture #2. The tests were conducted for approximately 3-4 months. Data collected during the lab study included monthly sampling for sulfate, electron donor, chlorinated compounds, ethene, ethane, and methane.

The success criterion for this performance objective was production of ethene at concentrations at least 2X detection, and reduction of TCE by at least 95 percent in the microcosms. The results of the study showed that dechlorination of TCE to ethene was achieved in less than 4 months, with nearly complete removal of TCE. Therefore, this performance objective was met. The full discussion of the results related to this performance objective is presented in Section 6.1.1.

3.1.2 Select Bioaugmentation Culture with Reliable Biomarker

Another concern for implementation of the demonstration is that the site might have already contained *DHC* prior to the demonstration, which would make tracking of the introduced bacteria difficult. In order to address this concern, samples of site groundwater were collected from MW-70-27 and EW-70-01 and analyzed for *DHC* DNA. In addition, three commercially available bioaugmentation cultures were screened and DNA was sequenced in order to select a bioaugmentation culture that could be reliably distinguished from any indigenous species.

The success criterion for this objective was identification of a biomarker that is present in bioaugmentation culture(s) but not in native *DHC*. The results from the DNA study showed that the functional gene *vcrA* was not present at the site, but was present in a commercially available bioaugmentation culture. Therefore, this performance objective was met. The full discussion of the results related to this performance objective is presented in Section 6.1.2.

3.2 PHASE 2 PERFORMANCE OBJECTIVES – BASELINE CONDITIONS AND PRE-CONDITIONING

The purpose of Phase 2 of the ER-0513 project was to determine groundwater hydraulic conditions and baseline contaminant distribution, *DHC* distribution, and geochemical concentrations prior to beginning the biostimulation and bioaugmentation in each treatment cell. Performance objectives were established related to demonstrating that the treatment cell layout was such that meaningful results could be obtained during the timeframe of the project, and related to establishing appropriate conditions prior to conducting bioaugmentation. These objectives are discussed further below.

3.2.1 Treatment Cell Construction and Residence Time

Due to the slow ambient groundwater velocity in the Site 70 source area, ESTCP was concerned that effects of electron donor injections and bioaugmentation would not be observed at monitoring wells within the timeframe of the demonstration, at least for the passive cell. In

addition, historical data that were available for the site did not provide conclusive information regarding groundwater flow magnitude and direction in the Upper Fines unit (see Section 4.2.2) on the scale of the source area. In order to verify that meaningful results could be obtained using the proposed treatment cell layout, a tracer test was conducted to verify the groundwater hydraulic conditions in the treatment cells. Data collected in support of this objective were multiple iodide tracer samples collected from active cell and passive cell monitoring wells.

The success criterion for this objective was to construct the treatment cells such that travel time from injection wells to monitoring wells was 6 months or less. The results of the tracer test showed arrival in some wells in less than 1 month, and subsequent sampling for tracer indicated that travel times to most monitoring wells were less than 4 months. These results were documented in a memo to ESTCP dated June 6, 2008 (see Appendix B). Therefore, this performance objective was met. The full discussion of the results related to this performance objective is presented in Section 6.2.1.

3.2.2 Pre-Conditioning Results

Baseline sampling was conducted to assess baseline conditions including contaminant and degradation product concentrations, redox parameters, and biological activity indicators (refer to Section 5.2 for complete baseline sampling results). In summary, the baseline results confirmed the pre-demonstration conditions in the source area, namely that conditions were anaerobic but mildly reducing, with very high sulfate concentrations and very limited dechlorination to *cis*-DCE in some areas. Because these conditions were not ideal for bioaugmentation, electron donor additions were performed to "pre-condition" the aquifer to reduce sulfate concentrations and to drive redox conditions more strongly reducing. Data collected in support of this objective included redox-sensitive parameters (specifically sulfate, ferrous iron, and methane), electron donor (as COD), volatile organic compounds (VOCs), and *DHC* using qPCR.

The success criterion for this objective was to create at least sulfate-reducing conditions at monitoring wells nearest to injection locations, such that the bioaugmentation culture would have a favorable environment following inoculation. Results showed that redox conditions nearest the injection locations were sulfate reducing to methanogenic in both treatment cells following the pre-conditioning phase. These results were documented in a memo to ESTCP dated December 28, 2008 (see Appendix B). Therefore, this performance objective was met. The full discussion of the results related to this performance objective is presented in Section 6.2.2.

3.3 PHASE 3 PERFORMANCE OBJECTIVES – BIOAUGMENTATION RESULTS

The purpose of Phase 3 of the ER-0513 project was to demonstrate full-scale bioaugmentation and dechlorination using both the active and passive approaches. Phase 3 of the ER-0513 project began with inoculation of both treatment cells. Performance objectives were established related to collection of data that would allow for quantification of bacterial distribution and growth, and assessment of the extent of dechlorination. These objectives are discussed further below.

3.3.1 Bacterial Growth and Distribution

The first Phase 3 objective was to assess and quantify bacterial growth and distribution in both treatment cells. Bacterial distribution was assessed by analyzing the first arrival of *DHC* bacteria (as measured by qPCR analysis) at a giving monitoring location following inoculation. This travel time was then compared to the travel time for ambient groundwater, as determined from the tracer test. Bacterial growth was then assessed by analyzing the increase of *DHC* and functional gene counts at a given location once first arrival had been established. Data collected in support of this objective included concentrations of *DHC* using qPCR and iodide tracer.

The success criterion for this objective was to collect data that allow for quantitative assessment of tracer and bacterial transport time, and growth of bacteria over time. No specific criteria were set in terms of bacterial transport times or cell counts. Therefore, this performance goal was met. The full discussion of the results related to this performance objective is presented in Section 6.3.1.

3.3.2 Extent of Dechlorination

The second Phase 3 objective was to assess and quantify the extent of dechlorination using both the active and passive bioaugmentation approaches. In the ER-0513 work plan, decision rules were defined for this performance objective based on trends observed in monitoring data, as shown in Table 3-2:

Table 3-2. Decision Rules for Dechlorination Performance Objective

	Redox Conditions	Chloroethenes	Ethene	qPCR
Favorable trends	Sulfate decreasing or absent; Methane detected	Decreasing or not detected	Increasing or molar equivalent to initial TCE	*DHC* bacteria detected
Unfavorable trends	Sulfate present and not decreasing; no methane detected	Stable or increasing	Not detected	No *DHC* bacteria detected

Decision Rule 1: If the passive treatment cell shows all of the favorable trends in Table 3-2 at >2/3 of all monitoring wells, then it will be determined that full-scale bioaugmentation was successfully implemented using the passive approach. If less than 1/2 of all monitoring wells in the passive cell show all favorable trends in Table 3-2, then it will be determined that full-scale bioaugmentation was not successfully implemented using the passive approach. If more than 1/2 but less than 2/3 of all monitoring wells show favorable trends, then further evaluation will be required.

Decision Rule 2: If the active recirculation treatment cell shows all of the favorable trends in Table 3-2 over a distance of greater than or equal to 75 feet from the reinjection wells, then it will be determined that full-scale bioaugmentation was successfully implemented using the active recirculation approach. If the active recirculation treatment cell does not show all of the favorable trends in Table 3-2 over a distance of at least 50 feet from the reinjection wells, then it will be determined that full-scale bioaugmentation was not successfully implemented using the

active recirculation approach. All other combinations of potential outcomes will require further evaluation.

A third decision was identified in the Demonstration Plan, to determine whether, and to the extent possible, under what conditions the passive approach is more technically effective and cost effective than the active recirculation approach. Decision #3 is based on the outcomes of Decisions 1 and 2, as well as on cost. Because of the multiple combinations of outcomes, and because of the fact that Decision Rules 1 and 2 are qualitative and are based on trends rather than explicit action levels, no decision rule was presented for Decision #3. However, an overall evaluation was made considering all available data in order to determine whether the passive approach was more technically effective and more cost effective than the active approach. This discussion is presented in Section 6.

Based on these decision rules, data collected in support of this performance objective include chloroethene and dissolved gas concentrations; stable carbon isotope analysis, redox sensitive parameters, and DHC using qPCR. The success criterion for this performance objective was to achieve full dechlorination to ethene using both approaches, as indicated by detection of ethene at greater than 2X detection limit at greater than or equal to 2/3 of the monitoring wells in a given treatment cell. Based on data collected during Phase 3, this performance objective was partially met. The full discussion of the results related to this performance objective is presented in Section 6.3.2.

3.4 QUALITATIVE PERFORMANCE OBJECTIVES

One qualitative performance objective was established for the ER-0513 project. This objective was to assess the ease of use for both passive and active approaches. This includes operational time required in the field, time spent conducting maintenance and repair activities, and the amount of training required to operate each system. Data collected in support of this objective include feedback from field personnel; injection and operational logs, and the field team leader logbook.

The success criterion for this performance objective was to quantify the operational requirements for each approach. Data collected during the course of the ER-0513 demonstration did allow for an assessment of the ease of use of both approaches. Therefore, this performance goal was met. The full discussion of the results related to this performance objective is presented in Section 6.4.

4.0 SITE DESCRIPTION

This site description includes a discussion of the site location and history, geology and hydrogeology, geochemistry, and contaminant distribution. This includes site background conditions at the outset of the demonstration project, not including baseline characterization activities. Results of baseline sampling are provided in Section 5.2.

4.1 SITE LOCATION AND HISTORY

NAVWPNSTA IR Site 70 was the former National Aeronautics and Space Administration (NASA) Research Testing and Evaluation Area, a rocket engine test facility located just south of Westminster Boulevard and east of Seal Beach Boulevard in Seal Beach, California (Figure 4-1). Site 70 encompasses approximately 40 acres on the northwestern quadrant of the NAVWPNSTA Seal Beach. Site 70 includes seven office and production buildings, asphalt-paved parking areas, several aboveground storage tanks, and distribution pipelines.

Past operations at the facilities reportedly included the use of dilute acids, chlorinated solvents including TCE, phenolic compounds, petroleum oils, sodium dichromate containing hexavalent chromium (Cr^{6+}), detergents, paint waste containing metals, volatile organics, and machine lubricating oil (Naval Weapons Station Seal Beach, 2005). Currently these facilities are being used for industrial operations, storage, communications research, and office space.

4.2 GEOLOGY AND HYDROGEOLOGY

4.2.1 Regional Geology

Most of NAVWPNSTA Seal Beach slopes evenly from approximately 20 feet above sea level in the northwestern part of the facility to sea level at the tidal flats of the Seal Beach National Wildlife Refuge in the southeast. NAVWPNSTA Seal Beach is located on the Los Angeles-Orange County coastal plain and is underlain by approximately 20,000 feet of alluvial deposits. Recent age alluvial and coastal deposits overlay the NAVWPNSTA Seal Beach area.

4.2.2 Site-Specific Geology

The most recent characterization events at the site were conducted as a part of Remedial Design Optimization (RDO) activities in 2005 by GeoSyntec Consultants (GeoSyntec Consultants, 2006). The RDO included cone penetrometer (CPT) soil and groundwater sampling within the Site 70 source area, as well as other characterization and testing activities in the downgradient plume area. Based on boring logs and site geologic models (GeoSyntec Consultants, 2006), the following hydrostratigraphic units, in order of increasing depth, have been characterized beneath NAVWPNSTA IR Site 70:

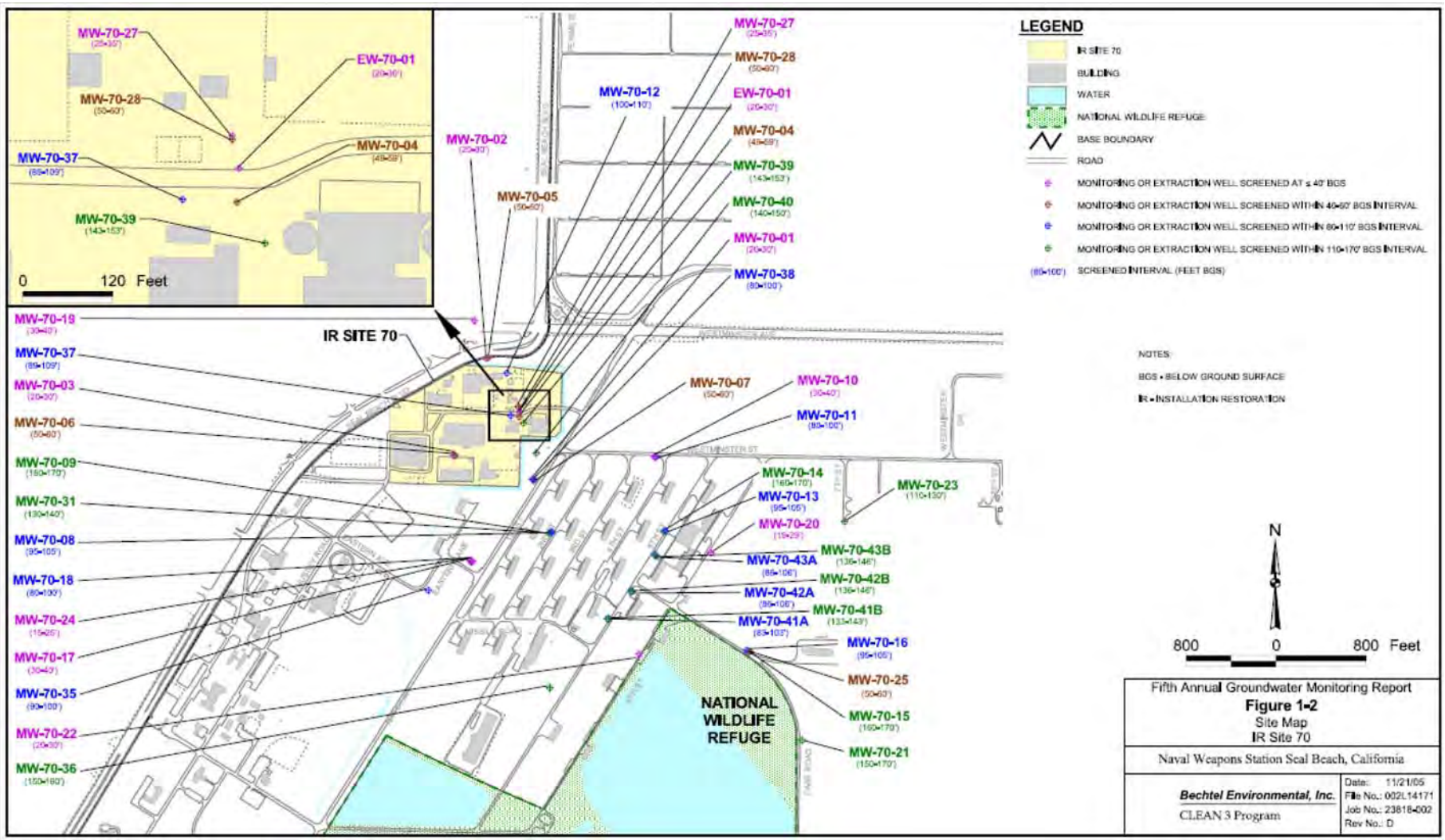

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Figure 4-1
BECHTEL SITE LOCATION MAP
NAVWPNSTA SEAL BEACH, SITE 70
SEAL BEACH, CALIFORNIA

- **Upper Fines Unit.** This unit extends from ground surface to approximately 60 feet below ground surface (bgs) and comprises three zones: a shallow zone of surficial soils and recent clayey sediments; an intermediate zone of interbedded silts, clays, and sandy silts and clays including a semi-perched zone; and a lower zone of interbedded silts, clays, and fine to coarse-grained, silty to clayey sands. Based on CPT boring logs from the RDO activities, fine to medium grained sands are present from approximately 20 to 30 feet bgs in the source area. These sands are underlain by a clay unit to about 40 feet bgs.
- **First Sand Unit.** This unit extends from approximately 60 to 105 feet bgs. It consists of poorly-graded fine-grained sands and silty sands. A coarse sand/fine gravel layer is present between 80 and 95 feet bgs in some areas.
- **Shell Horizon.** The shell horizon extends from approximately 105 to 135 feet bgs and comprises interbedded clays, silts, sands, and gravels below the source area transitioning to mainly fine-grained sand to the southeast. This unit was subdivided into two zones: interbedded clays and fine-grained sands.
- **Second Sand.** This unit is similar to the First Sand unit and extends from approximately 135 to 170 feet bgs.
- **Deep Clay Unit.** This unit extends from approximately 170 to 190 feet bgs and appears to be a continuous unit throughout the entire area of Site 70.
- **Deep Sand Unit.** This unit is encountered at approximately 190 feet bgs and appears to be similar in character to the First and Second Sands.

It should be noted the site specific geology presented above differs from what is described in the Final Extended Removal Site Evaluation Report (Bechtel Environmental, Inc., 1999) in that the Upper Fines Unit is separated into three separate units – the Surficial Soils, Shallow Clay Unit, and the Interbedded Unit.

4.2.3 Hydrogeology

The principal source of the deposited alluvium referenced above is the San Gabriel River, which cuts through the coastal plain creating the Alamitos and Sunset Gaps. Groundwater flows preferentially through the gaps due to the higher permeability of the alluvial fill within them. Regional groundwater flow is also influenced by the Los Alamitos injection barrier, tidal influences, groundwater production wells, and manmade recharge basins (Jacobs Engineering Group, 1994).

Groundwater occurrence has been described as semi-perched and unconfined in the fine grained silt and silty sand that generally comprises the upper 60 feet of the Recent Age deposits. Confined freshwater zones have been identified at depths of 75 and 200 feet bgs at NAVWPNSTA Seal Beach and at depths of 250 to 1,000 feet bgs beneath NAVWPNSTA Seal Beach and neighboring cities (Jacobs Engineering Group, 1994).

This demonstration was conducted in the contaminant source area in the Upper Fines Unit, from approximately 15 feet bgs to 35 feet bgs. The water table in the source area was historically

present at 5 to 12 feet. Hydraulic conductivity was not directly measured during the RDO. Based on historical data, the estimated conductivity in the Upper Fines Unit is 10 ft/d (Bechtel Environmental, Inc., 1999).

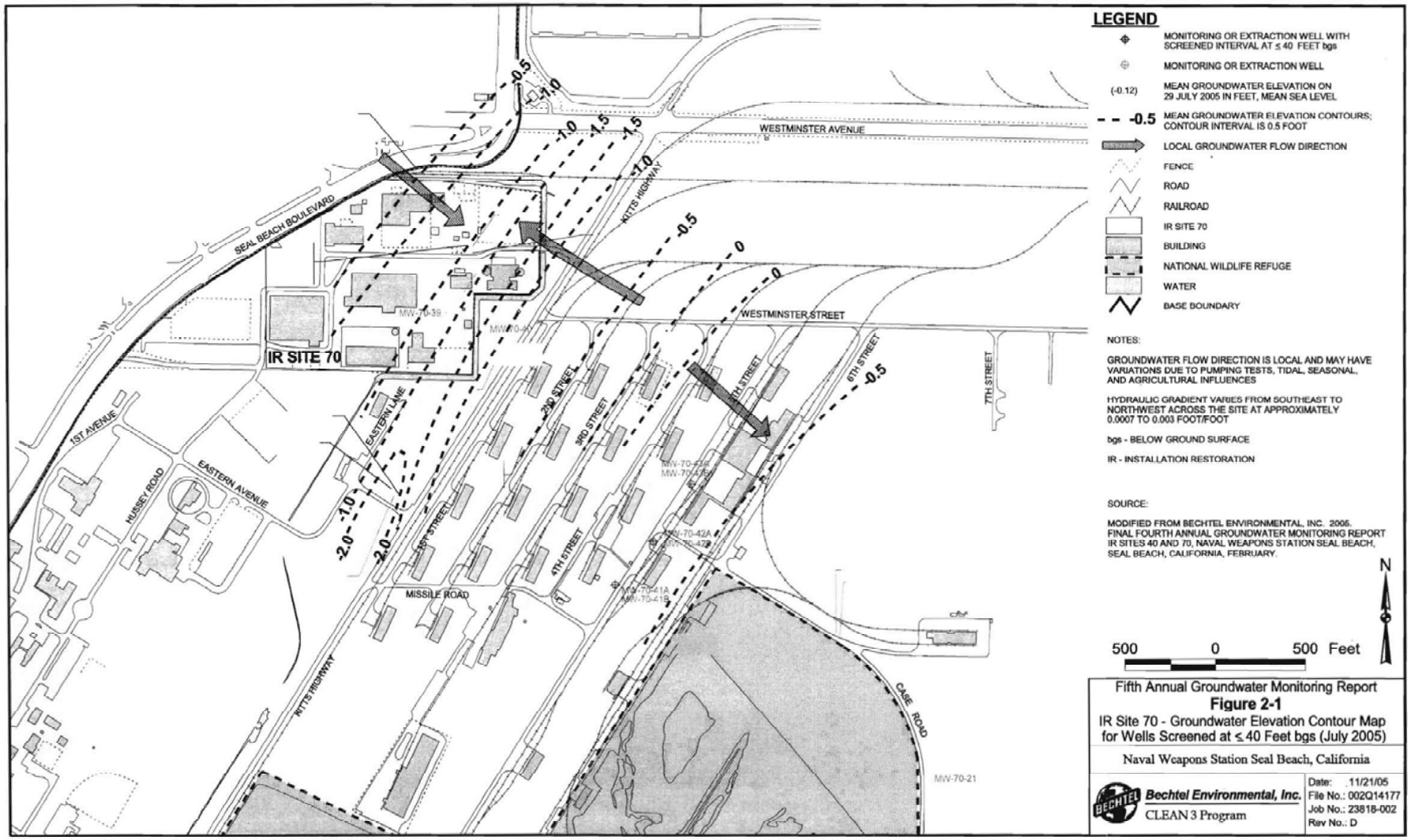
Sitewide historical hydraulic gradients in the Upper Fines Unit range from 0.0002 to 0.0011. However, hydraulic gradients within the contaminant source area from 0-40 feet bgs are confounding, as described in a recent groundwater monitoring report for Site 70 (Bechtel Environmental, Inc., 2005). Groundwater level data from July 2005 are shown as Figure 4-2, which is taken from (Bechtel Environmental, Inc., 2005). Figure 4-2 shows that groundwater flows generally northwest to southeast and culminates in a southwest-to-northeast trough in the general area of EW-70-01. The occurrence of the trough is attributed to an old stream drainage system that flowed through IR Site 70 (Bechtel Environmental, Inc., 2005). Groundwater flow in areas northwest of this trough is to the southeast into the trough, which is consistent with flow directions in deeper aquifer zones at Site 70. However, in areas that are southeast of the trough, groundwater actually flows northwest into the trough, with a gradient within the same range as the overall gradients for the Upper Fines Unit. Once groundwater reaches the trough, it appears to flow to the southwest (Bechtel Environmental, Inc., 2001), although the resolution of water level measurements in the source area may not be sufficient to fully characterize the flow direction.

Also, quarterly water level data collected during 2004 and 2005 show that water levels vary seasonally at Site 70 by nearly 7 feet. However, the occurrence of the trough near the Site 70 source area was observed in all quarters of monitoring, although its inferred location was slightly further southeast during the December 2004 sampling round (Bechtel Environmental, Inc., 2005).

It is important to note that while this trough was observed during multiple groundwater sampling rounds, the number of data points used to create the historical groundwater elevation maps is not sufficient to elucidate detailed hydraulic gradients on the scale of source area (i.e., 200-400 feet). For example, the site-wide elevation maps from (Bechtel Environmental, Inc., 2005) show the entire source area as having the same groundwater elevation, which would imply that no groundwater flows through the source area (Figure 4-2). However, the gradient between wells EW-70-01 and MW-70-27 ranges from 0.0012 to 0.0026, with the flow direction toward MW-70-27, suggesting that the location of the trough may be closer to MW-70-27 than to EW-70-01, as suggested in Bechtel Environmental, Inc. (2005).

4.3 GEOCHEMISTRY

Redox conditions in the source area, as measured in July 2005 (Bechtel Environmental, Inc., 2005), were mildly reducing, with oxidation/reduction potential (ORP) ranging from 56 to 179 mV. Dissolved oxygen (DO) was less than 0.5 mg/L, and some ferrous iron was detected in source area well EW-70-01, at 1.25 mg/L. One unique attribute of Site 70 is very high levels of sulfate in the source area. In source area well MW-70-27, sulfate was 7,650 mg/L; however, approximately 50 feet away at EW-70-01, sulfate was 1,150 mg/L, indicating that the very high concentrations are localized around MW-70-27. Consistent with the high levels of sulfate, methane was not detected above 110 µg/L.



page 2-3

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Figure 4-2
BECHTEL GROUNDWATER ELEVATION MAP
NAVWPNSTA SEAL BEACH, SITE 70
SEAL BEACH, CALIFORNIA

Chloride is also high in the source area, with MW-70-27 having a concentration of 3,920 mg/L. As with the sulfate, chloride decreases significantly from this well to EW-70-01, which had a concentration of 577 mg/L. Total organic carbon is low throughout the aquifer, with concentrations ranging from 0.5 mg/L to 14.8 mg/L. This is consistent with the limited dechlorination that has occurred intrinsically at this site (see Section 4.4). Alkalinity in the source area is 500-660 mg/L as $CaCO_3$, indicating that the aquifer has a reasonable buffering capacity.

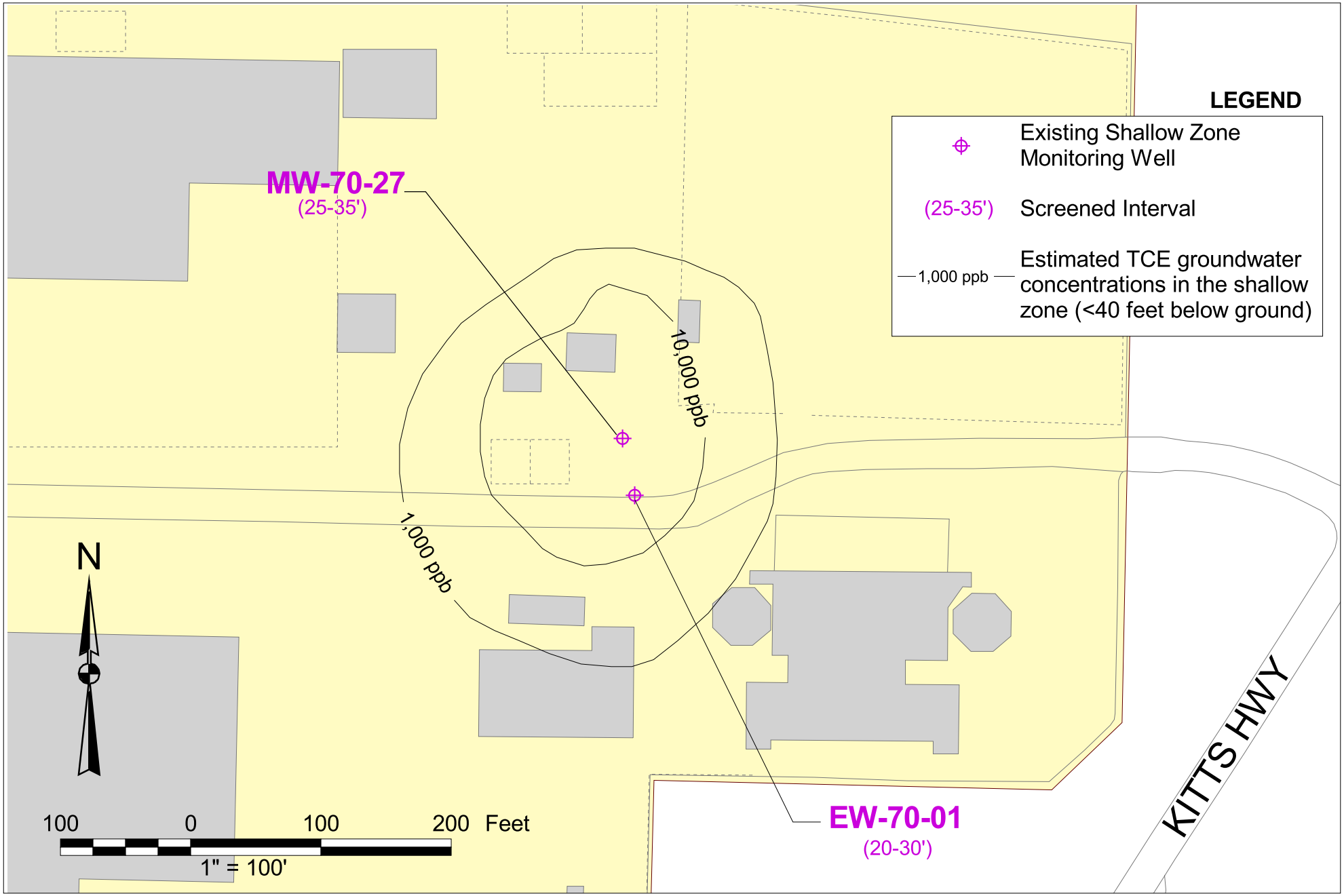
Overall, it appears as though the chemical oxidation activities that were conducted near MW-70-27 have significantly increased sulfate and chloride concentrations locally, and have created less reducing (although still anaerobic) conditions compared to the rest of the source area. This is confirmed by the fact that none of the source area RDO groundwater samples had sulfate or chloride concentrations of more than 1000 mg/L. Because of this, the geochemistry of EW-70-01 is thought to be more representative of the overall conditions in the source area.

4.4 CONTAMINANT DISTRIBUTION

The groundwater plume at Site 70 contains primarily TCE and other VOCs such as PCE, DCE, VC, chloroform, and others (Bechtel Environmental, Inc., 2005). The plume is estimated to be approximately 2,400 feet long by 2,000 feet wide and approximately 195 feet deep. There are two parts to the VOC plume: a small, high concentration source zone and a large area consisting of lower concentration VOCs in the dissolved-phase. The location for this demonstration is the shallow source zone, and the estimated extent of TCE in the source zone is shown in Figure 4-3.

Wells MW-70-27 and EW-70-01 are the only Upper Fines Unit permanent monitoring wells in the source area. These wells are completed from 25-35 feet bgs (MW-70-27) and from 20 to 30 feet bgs (EW-70-01). Each of these wells has very high levels of TCE, as concentrations in July 2005 were 130 mg/L and 53 mg/L, respectively. Concentrations of other chloroethenes are much lower in MW-70-27, where *cis*-DCE was 670 µg/L, and VC and ethene were each less than 25 µg/L. The most significant concentrations of daughter products were measured at EW-70-01, which had *cis*-DCE at 27 mg/L, while VC was 720 µg/L.

The RDO involved collection of groundwater samples through temporary CPT wells throughout the source area. However, these samples were all collected at depths of 45-60 feet bgs, which represent the lower part of the Upper Fines Unit. The highest TCE concentration measured during the RDO sampling was 4 mg/L. This, combined with the data from MW-70-27 and EW-70-01, indicates that the high contaminant concentrations are limited to depths shallower than 40 feet bgs, which is the target zone for this demonstration. Overall within the source area, while some limited dechlorination has occurred, the majority of contamination in the source area is present as TCE.



* Note - Concentration contours from Geosyntec Consultants 2005 Draft Technical Memorandum.
Contours are based on September 2005 permanent monitoring wells groundwater concentrations including MW-70-27 and EW-70-01.

CDM

FIGURE 4-3
ESTIMATED TCE SOURCE ZONE CONCENTRATIONS
NAVWPNSTA SEAL BEACH IR SITE 70
SEAL BEACH, CALIFORNIA

5.0 TEST DESIGN

This section provides the detailed description of the system design and testing conducted during the demonstration. This includes the conceptual design, treatability studies, system installation, baseline characterization, bioaugmentation, and monitoring. The sampling and analysis is described in Section 5.7. The results of these activities are presented throughout this section, with the results of all Phase 3 activities being presented in Section 5.8. Discussion and interpretation of the key results is provided in Section 6.

5.1 CONCEPTUAL EXPERIMENTAL DESIGN

The overall experimental design is based on the performance objectives presented in Section 3. The design comprised two independent treatment cells to test the passive and active bioaugmentation approaches in a side-by-side comparison. The passive treatment cell consists of three injection wells, three multilevel (Continuous Multichannel Tubing [CMT]) monitoring wells, and six standard monitoring wells. The active recirculation cell consists of two injection wells, two extraction/recirculation wells, three multilevel (CMT) monitoring wells, and three standard monitoring wells.

The design was performed in three phases as described below:

Phase 1 – Pre-Demonstration Laboratory Investigations. Bench-scale testing was performed to demonstrate that the bioaugmentation culture could overcome the high sulfate concentrations at the site. DNA analysis of site groundwater samples and commercially available cultures, including qPCR, clone library development, and DNA sequencing were used to identify "biomarkers" that provided the ability to differentiate between the injected cultures and any existing *DHC* that may have naturally existed in the groundwater.

Phase 2 - Tracer Test, Baseline Sampling, and "Pre-Conditioning". Following treatment cell construction, a tracer test was conducted in each of the treatment cells to verify the groundwater hydraulics in the shallow aquifer. Following the tracer test, baseline sampling was conducted to assess baseline conditions including contaminant and degradation product concentrations, redox parameters, biological activity indicators, and *DHC* concentrations. Following baseline sampling, electron donor was injected into each treatment cell to create strongly reducing conditions and remove sulfate prior to bioaugmentation.

Phase 3 – Bioaugmentation and Monitoring. This third and final phase involved injecting the dechlorinating culture into each of the two treatment cells and performing groundwater monitoring to compare with results from Phase 2.

5.2 BASELINE CHARACTERIZATION

The objectives of the baseline characterization were to determine groundwater hydraulic conditions and baseline contaminant distribution, *DHC* distribution, and geochemical concentrations prior to beginning the biostimulation and bioaugmentation in each treatment cell. In order to perform the baseline characterization, the active recirculation system and select

monitoring wells were installed prior to baseline activities. The remaining wells were installed based on observed water levels during ambient and pumping conditions. Details of the recirculation system and well installations are provided in Section 5.4.

A tracer test was then conducted in the active cell to verify the groundwater hydraulic conditions in the treatment cells. In order to create similar conditions to the demonstration, the recirculation system was started 5 days prior to starting the tracer test and continued operating during baseline sampling. Following the tracer test, the additional wells were installed and baseline sampling was conducted to assess baseline conditions including contaminant and degradation product concentrations, redox parameters, and biological activity indicators. A summary of these activities is provided below.

5.2.1 Installation Activities

Well installation was not performed in one mobilization because the groundwater flow patterns needed to be understood with the active cell recirculation system running. Once the groundwater flow pattern under pumping conditions was understood, the most appropriate cell orientation was determined for the passive cell. This phased approach for treatment cell construction allowed for the opportunity to assess groundwater flow direction in the area of the planned passive cell wells before installing the remaining ten wells. This helped avoid a scenario in which the entire passive treatment cell was installed, only to find out that groundwater did not flow parallel to the treatment cell axis.

5.2.1.1 Active Cell Well Installation

Injection, extraction, and monitoring wells for the active cell were installed in September and October 2007, along with two of the passive cell monitoring wells. The active cell recirculation system itself was constructed, installed, and tested in March and April 2008. The system operated by extracting groundwater from wells AEW-1 and AEW-2 into a 275 gallon surge tank; the surge tank water was reinjected into AIW-1 and AIW-2, which is a distance of 100 feet upgradient from the extraction wells (refer to Figure 5-1 for well locations). Photos of the recirculation system are included in Appendix C. Once the system was functional, it was operated for several days, and water levels were measured in active cell monitoring wells, and in the two existing passive cell monitoring wells, in order to determine the groundwater flow direction in the area of the proposed passive cell wells. Synoptic water level data were collected in several wells using transducers, and in other wells by taking water levels using a water level meter.

Following a tracer study with the active cell running, the location of the passive treatment cell was modified to reflect the groundwater flow direction under pumping conditions. A more detailed description of the active cell tracer study is provided in Section 5.3.2 and in Appendix B. The groundwater flow direction was different than assumed based on data available at the time the ESTCP Demonstration Plan was submitted. The final well construction locations and details are shown in Table 5-1.

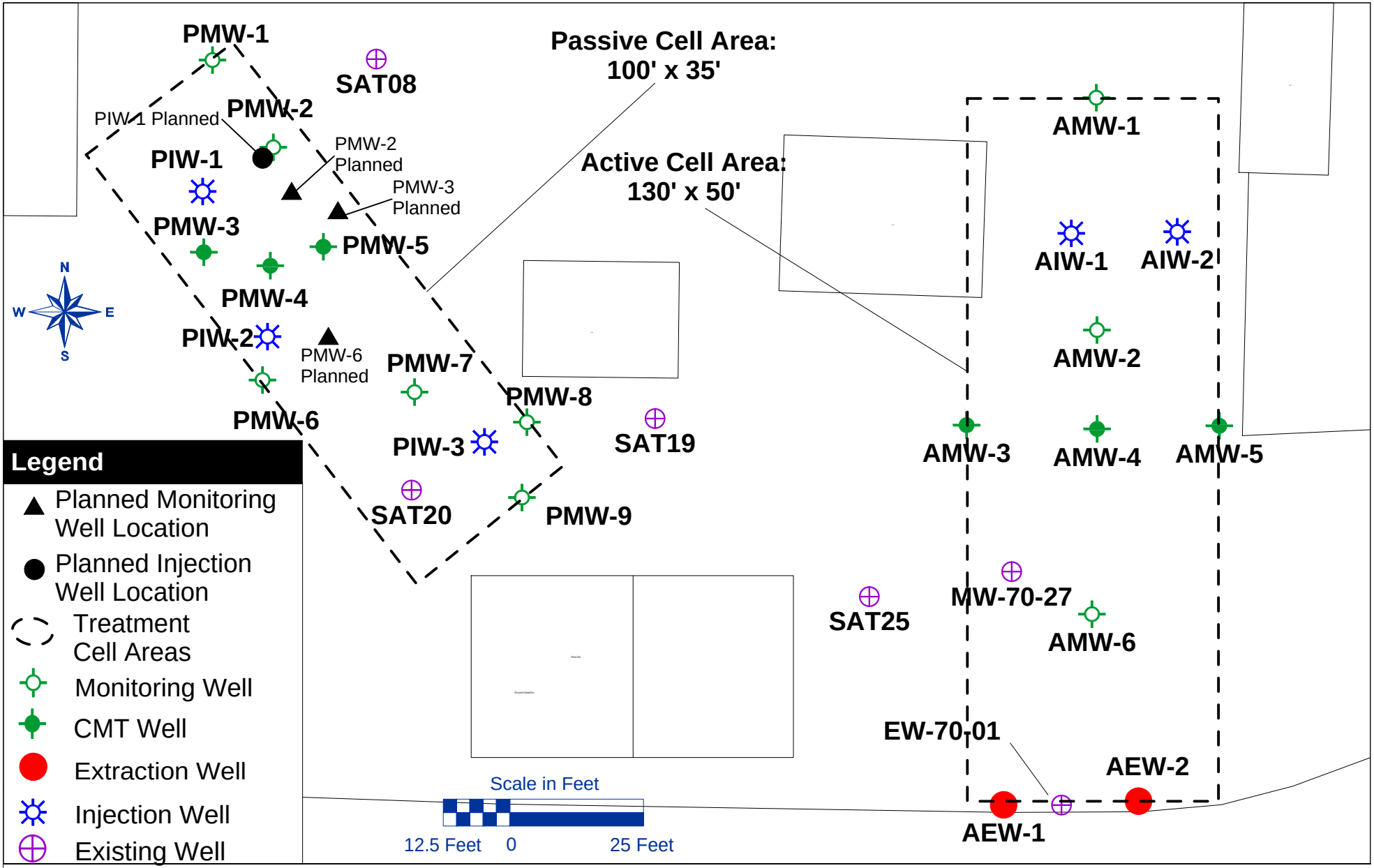


FIGURE 5-1
WELL LOCATION MAP
ER-0513 FINAL REPORT
SEAL BEACH NAVAL WEAPONS STATION, SEAL BEACH, CA

Table 5-1. Well Construction Summary

Well ID	Well Type	Easting	Northing	Surface Elevation	Construction	Well	Screen Interval	Total Depth
		UTM (feet)	UTM (feet)	NVD88 (feet AMSL)		Diameter	ft bgs	ft bgs
Passive Cell								
PMW-1	Monitoring	6005842.00	2224265.34	11.22	PVC	4-inch	15-35	35.3
PMW-2	Monitoring	6005853.47	2224248.64	11.69	PVC	4-inch	15-35	35.5
PMW-3	CMT - Zone 1	6005840.36	2224229.27	11.50	CMT	1.7-inch	34-35	36
	CMT - Zone 2						26-27	
	CMT - Zone 3						22-23	
	CMT - Zone 4						16-17	
PMW-4	CMT - Zone 1	6005852.88	2224226.69	11.43	CMT	1.7-inch	33.5-34.5	36
	CMT - Zone 2						30-31	
	CMT - Zone 3						26.5-27.5	
	CMT - Zone 4						22.5-23.5	
	CMT - Zone 5						15.5-16.5	
PMW-5	CMT - Zone 1	6005862.70	2224230.18	11.46	CMT	1.7-inch	33.5-34.5	35.9
	CMT - Zone 2						27-28	
	CMT - Zone 3						23-24	
	CMT - Zone 4						17-18	
PMW-6	Monitoring	6005851.40	2224205.28	11.20	PVC	4-inch	15-35	35.5
PMW-7	Monitoring	6005879.93	2224203.13	11.32	PVC	4-inch	15-35	35.5
PMW-8	Monitoring	6005900.79	2224197.53	11.23	PVC	4-inch	15-35	35.5
PMW-9	Monitoring	6005899.76	2224183.81	10.88	PVC	4-inch	15-35	35.5
PIW-1	Injection	6005840.29	2224240.54	11.63	PVC	4-inch	15-35	35.5
PIW-2	Injection	6005852.43	2224213.43	11.22	PVC	4-inch	15-35	35.5
PIW-3	Injection	6005892.86	2224193.80	11.27	PVC	4-inch	15-35	35.5
Active Cell								
AMW-1	Monitoring	6006006.90	2224258.32	10.60	PVC	4-inch	15-35	36.5
AMW-2	Monitoring	6006007.00	2224215.03	10.65	PVC	4-inch	15-35	36
AMW-3	CMT - Zone 1	6005982.69	2224197.30	10.53	CMT	1.7-inch	33-34	36.5
	CMT - Zone 2						28-29	
	CMT - Zone 3						24-25	
	CMT - Zone 4						17-18	
AMW-4	CMT - Zone 1	6006007.03	2224196.59	10.30	CMT	1.7-inch	33-34	36
	CMT - Zone 2						28-29	
	CMT - Zone 3						24-25	
	CMT - Zone 4						18-19	
AMW-5	CMT - Zone 1	6006029.84	2224197.17	9.83	CMT	1.7-inch	33-34	36.4
	CMT - Zone 2						28-29	
	CMT - Zone 3						24-25	
	CMT - Zone 4						18-19	
AMW-6	Monitoring	6006006.08	2224162.08	10.17	PVC	4-inch	15.5-35.5	35.5
AIW-1	Injection	6006002.22	2224233.05	11.01	PVC	4-inch	15-35	35
AIW-2	Injection	6006022.00	2224233.33	9.88	PVC	4-inch	15-35	35.6
AEW-1	Extraction	6005989.60	2224126.55	9.15	PVC	4-inch	15-35	35
AEW-2	Extraction	6006014.76	2224127.23	8.79	PVC	4-inch	15-35	35.3

CMT - Solinst® Continuous Multichannel Tubing System
UTM - Universal Transverse Mercator
NVD88 - National Vertical Datum 1988
ft bgs - feet below ground surface
AMSL – above mean sea level

5.2.1.2 Passive Cell Well Installation

In order to account for the more southerly flow direction under pumping conditions, placement of some of the passive cell wells was adjusted slightly from the original planned locations. These adjustments were made considering interpreted groundwater flow directions as well as accounting for the many underground utilities in the area. The planned and actual locations are presented in Figure 5-1. The most significant change was moving CMT well PMW-3 to be

directly south of PIW-1. The CMT wells are used to measure multiple depths from a single well using individual channels screened at discrete intervals. Also, well PMW-2 was moved from its planned location on the treatment cell axis to a location northeast of PIW-1. Finally, wells PIW-2 and PMW-6 were moved a few feet to the west of their planned locations in order to avoid utilities.

The remaining ten passive cell wells (four monitoring wells, three injection wells, and three CMT wells) were installed in April 2008 following the tracer test. After installation of the remaining passive cell wells, a new round of water level measurements was collected under pumping conditions.

5.2.1.3 CMT Well Installation

The ESTCP Demonstration Plan called for three sample ports in each CMT well. During installation of both the active and passive cell CMT wells, four sample ports were completed in all CMT wells except PMW-4, which has five sample ports. This was done in order to account for the possibility that some ports would not produce enough water for sampling.

5.3 BASELINE SAMPLING

Baseline sampling was completed in April 2008, after the active cell recirculation system was operating. In the active cell, this included sampling the three standard monitoring wells, all ports in the three CMT wells, and the water being produced from the extraction wells (refer to Figure 5-1 for well locations). Baseline sampling for the passive cell included sampling the six standard monitoring wells, all ports in the three CMT wells, and the three injection wells. Analytes sampled included VOCs, dissolved gases (ethene/ethane/methane), anions (sulfate, chloride, nitrate/nitrite), alkalinity, COD, DNA samples, compound-specific isotope analysis, and iodide tracer (for background measurements). A summary of the analyses performed in each monitoring well is provided in Section 5.6.

During the baseline sampling events, it was determined that the uppermost port in each active cell CMT well did not produce sufficient water to complete a full set of samples. However, because extra ports were installed in each well, data are available from multiple depths in each CMT well.

5.3.1 Baseline Sampling Results

Results of baseline sampling are summarized here and are presented in Table H-1 for the passive cell and Table I-1 for the active cell. For the active treatment cell, concentrations were generally around 1,000 to 3,000 µg/L for TCE, with other contaminants present at low levels, but concentrations increased significantly at the southern end of the cell. The highest concentration measured anywhere in the ESTCP demonstration area was 140,000 µg/L at well AMW-6. This is adjacent to a previous chemical oxidation pilot test and was known to be the highest concentration area within the source. The sample collected from the water being extracted from wells AEW-1 and AEW-2 had a TCE concentration of 10,000 µg/L.

For the passive cell, TCE concentrations were around 1,000 µg/L at each end of the treatment cell (wells PMW-1 and PMW-9). However, TCE concentrations were much higher in the center

of the passive cell (15,000 µg/L to 63,000 µg/L). Concentrations of other VOC contaminants were low in all passive cell wells.

Vertically discrete samples of contaminants in upper zones of the CMT wells in the active cell generally had low levels of contaminants and also produced very little water when purged. TCE concentrations were approximately 600 to 1,800 µg/L in middle to lower zones. For the passive cell, TCE concentrations are generally an order of magnitude higher than the active cell; upper zones had TCE concentrations of 1,000 to 10,000 µg/L, while middle and lower zones had TCE as high as 63,000 µg/L.

Results for other parameters show that the aquifer was generally mildly reducing with low levels of available carbon. DO was less than 1 mg/L and ferrous iron was generally less than 0.1 mg/L at all locations. Sulfate was very high at this site, with concentrations ranging from approximately 1,600 mg/L to as high as 8,700 mg/L near the area where the chemical oxidation pilot test was conducted. Methane was detected at some wells up to 230 µg/L, while COD ranged from non-detect to 100 mg/L. Overall, the pH was near neutral, and ORP ranged from -150 to +300 mV. The only exception to these general trends was well PMW-9, which had relatively high concentrations of methane of 2.8 mg/L, and somewhat depressed sulfate of 1,100 mg/L. While TCE was lower at this location than others in the passive cell, very low concentrations of reductive daughter products were present, and COD was low as well (16 mg/L). This suggests that while redox conditions may have been approaching methanogenesis at this location, little dechlorination was occurring.

Finally, the baseline compound-specific isotope analyses results show that the TCE present near the active extraction wells was "heavier" than in other places. This implies that a mechanism which results in fractionation of TCE (i.e., preferential transformation of the TCE molecules with the "lighter" carbon-12 isotope) is or was active in the past in this area. This is consistent with the fact that this area of the site is near the former chemical oxidation pilot test, because chemical oxidation is known to cause fractionation of TCE, similar to what biodegradation causes. Thus, it appears that the effects of the chemical oxidation are still evident in the isotope signatures at this monitoring location. This was not expected to affect data interpretation for the ER-0513 demonstration because future biodegradation would cause further fractionation of TCE, and would also produce daughter products, whose isotope signatures could then be monitored over time.

5.3.2 Active Cell Tracer Test

In order to verify the groundwater velocities estimated based on existing data, a tracer test was conducted in the active cell using an iodide tracer. The purpose of the tracer test was to determine hydraulic properties of the active cell and its effect on hydraulics in the passive cell, and to measure the first arrival of tracer at the nearest monitoring locations, which represents the earliest expected arrival of injected bacteria and donor. In order to determine the hydraulic properties of the treatment cells, peak breakthrough had to be measured in at least one monitoring well for each treatment cell.

Approximately 500 gallons of potassium iodide was injected into the active cell on April 10, 2008. The average concentration of iodide in the injected solution was approximately

13,100 mg/L. Samples for iodide tracer were collected once per day from well AMW-2 for approximately 4 weeks. Periodic CMT monitoring was then performed for seven weeks after the tracer injection.

A detailed summary of the active cell tracer study is provided in Appendix B, including tracer breakthrough curves for the active cell tracer test. Tracer breakthrough was observed in AMW-2 (18 feet from injection wells) within 2 weeks. Breakthrough was observed at AMW-4 Zone 2 (screened 28 feet bgs) within approximately 2.5 weeks, Zone 1 (33 feet bgs) within 3 weeks, and Zone 3 (24 feet bgs) within 4 weeks. In addition, tracer breakthrough occurred in AMW-5 Zone 2 and AMW-3 Zone 3 in approximately 5 weeks, and tracer was eventually detected in the other ports in these CMT wells. These results showed that the deeper zones are more transmissive, which is also where the higher contaminant concentrations are found in these wells. The long tail on the AMW-2 tracer breakthrough curve is likely the result of different tracer arrival times in the various lithologic units.

A preliminary analysis of the tracer test data was performed in order to estimate aquifer properties for the purpose of calculating potential ranges of travel times within the passive cell. The model used was developed for an instantaneous point source (Baetsle, 1969). The analytical equation is found in Domenico and Schwartz (1990, p. 650). A hydraulic conductivity of 10 ft/d was assumed as a starting point based on a pumping test performed in the source area at the site several years ago. An effective porosity of 0.20 was assumed based on CDM's experience with this soil type. A longitudinal dispersivity value equivalent to approximately 10 percent of the scale of the cell was assumed, and the transverse dispersivity was assumed to be 10 percent of the longitudinal. The hydraulic gradient used was 0.04 based on water level measurements during pumping. The final variable in this model is distance from the axis (or centerline) of transport. Given the two injection wells in the active cell, this analytical model does not perfectly represent the real system, and the distance from the axis has a questionable meaning. Also, solutions using this model will be non-unique as multiple combinations of the conductivity, effective porosity, and distance from the centerline can produce very similar results. Nevertheless, it is believed that this approach is useful to estimate aquifer properties reasonably, especially given the fact that the hydraulic conductivity has previously been measured by a multiple well pumping test at the site.

Using this approach, inverse modeling was performed to estimate a range of hydraulic conductivities based on matching model predictions to measured iodide breakthrough at several of the monitoring locations. For the three active cell monitoring locations shown, the hydraulic conductivity ranged from 5 to 10 ft/d. Thus, the tracer test data could be reasonably matched using hydraulic property values consistent with the soil type and previous hydraulic testing at the site.

Based on the estimated values of parameters determined by the tracer test as listed above, travel times from passive cell injection wells to passive cell monitoring wells were estimated. The most significant factor affecting the travel time is the injection event itself. The target injection volume of 1,000 gallons per well is based on achieving a radius of influence of 5 feet. Therefore, it was assumed that the injected substrate would be distributed 5 feet from the injection point at time zero. Given the range of hydraulic conductivities that were estimated based on the tracer

test, along with the measured groundwater elevations, groundwater velocity in the passive cell was expected to be approximately 4-8 feet/month, or 45-90 feet/year. This is well within the range of ambient groundwater velocity at other sites where bioremediation and bioaugmentation have been successful, and is in fact two to four times higher than what was originally assumed in the ER-0513 ESTCP Demonstration Plan.

The transport during injection combined with advection under ambient conditions results in travel times from injection wells PIW-1 and PIW-3 to their corresponding monitoring wells ranging from 1 to 3 months, assuming a hydraulic conductivity of 10 ft/d. Even if the low estimate of 5 ft/d for conductivity were assumed, travel times from PIW-1 and PIW-3 range from 2 to 5 months. Well PIW-2 has a monitoring well located 8 feet away (PMW-6), and another monitoring well located 29 feet away (PMW-7). Depending on the local flow direction in this area, travel times to PMW-6 could be less than one month, while travel times to PMW-7 could be 3 to 7 months. These travel times were deemed acceptable for the demonstration, and the data indicated that travel times were less than predicted (refer to Sections 5.8 and 6.3).

5.4 TREATABILITY AND LABORATORY STUDY RESULTS

The objectives of Phase 1 were to demonstrate that a commercially available bioaugmentation culture is able to perform complete dechlorination under high sulfate conditions, and also to choose a culture that can be differentiated from naturally existing bacteria in the groundwater at the site. These objectives were successfully met by performing bench-scale studies of the groundwater and analyzing the existing cultures in the groundwater using qPCR, clone library development, and DNA sequencing.

5.4.1. Bench-Scale Study

Site 70 is known to have sulfate and chloride concentrations in excess of 1,000 mg/L in the source area, likely due to past chemical oxidation activities. Sulfate-reducing bacteria can compete with dechlorinators for available electron donor, and high sulfate concentrations have been shown to inhibit complete dechlorination when the sulfate cannot be removed. For this reason, ESTCP requested bench-scale testing be performed to evaluate a commercially available bioaugmentation culture for its ability to overcome the high sulfate concentrations and dechlorinate TCE all the way to ethene.

Microcosm Study Setup

The purpose of the microcosm test was to determine whether either of two bioaugmentation cultures could achieve dechlorination in well samples from the NAVWPNSTA Site. The tests were performed by Bioremediation Consulting, Inc. (BCI) and the full report is provided as Appendix D.

CDM selected two wells for testing: (1) EW-70-01, which had a high chloride content of 2,200 mg/L and high sulfate content of 1,650 mg/L, and (2) MW-70-27, which had high chloride of 4,400 mg/L and extremely high sulfate of 9,300 mg/L. Both wells contained total chlorinated ethene concentrations of less than 30 mg/L.

Two *DHC* cultures were used for testing: Culture "S" (a TCE-degrader) and Culture "B" (a mixed chloroethene-degrader), both of which had capabilities with high chloride concentrations. Both cultures were augmented with a sulfate-reducing culture active at high sulfate concentrations.

Anaerobic microcosms were constructed to test each culture with each groundwater sample, using whey as an electron donor (food source), and adding small amounts of nutrients needed by bacteria (ammonia and phosphate), as well as yeast extract and vitamin B12. Killed control microcosms were also constructed for each well sample. Microcosms were monitored by removing small samples and analyzing for chlorinated organics and ethene by gas chromatography, and organic acids and sulfate by capillary ion electrophoresis.

Results and Conclusions

For EW-70-01, which contained 1,650 mg/L sulfate and 2,200 mg/L chloride, BCI Cultures "S" and "B" were equally successful in dechlorinating 16 mg/L TCE and 6 mg/L *cis*-DCE completely to ethene in 112 days. Ethene was measured as high as 177 µM, and sulfate was reduced to non-detect using both cultures. Figures showing results from the study are included in Appendix D.

For MW-70-27, which contained very high sulfate of 9,270 mg/L and very high chloride of 4,350 mg/L, Culture "S" succeeded in converting all of the TCE to VC (45µM) and ethene (119 µM) in 112 days (see Appendix D). Sulfate was reduced by 36 percent to 6,020 mg/L during this time. Culture "B" was able to degrade all of the TCE present in the microcosm, but dechlorination only proceeded to cis-DCE and VC, with trace amounts of ethene produced. Sulfate was reduced by 35 percent to 5,990 mg/L during this time. Based on these results, it was concluded that complete dechlorination to ethene was achievable in the presence of the high sulfate concentrations at the site.

5.4.2 DNA Sequencing Study

Another concern for implementation of the demonstration was that the site might already contain *D. ethenogenes* or other *DHC* that would make tracking of the introduced bacteria difficult. In order to address this concern, samples of site groundwater were collected from MW-70-27 and EW-70-01 and analyzed for *DHC* DNA. The DNA was amplified using specific primers for *DHC*, then the amplified DNA was inserted into clones, from which the DNA was later extracted and sequenced. Up to 20 clones were analyzed in this clone library, allowing determination of the *DHC* strains that are present at the site. Results from this study are provided in Appendix D.

The results from the 16S rRNA clone library GenBank analysis suggest that most of the *DHC* identified in the NAVWPNSTA Site 70 and bioaugmentation clone libraries were most closely related to *Dehalococcoides ethenogenes* strain 195, or *Dehalococcoides* species TM-EtOH with greater than 98-99 percent sequence similarity. These data illustrate that the *DHC* 16S rRNA rRNA sequences are highly similar, and while there are some regions between different sequences that are significantly different, it would be difficult to distinguish between the observed sequences found within the different bioaugmentation cultures and those indigenous to the NAVWPNSTA Site 70 by 16S rRNA molecular analysis alone.

Baseline qPCR analysis showed that indigenous *DHC* were only detected at low levels at two monitoring locations – the active extraction wells had 448 ± 75 cells/L, and the passive cell well PMW-3 had 110 ± 28 cells/L. These cell counts are just above the minimum quantification level for the qPCR analysis, and are four to six orders of magnitude lower than what is typically observed following bioaugmentation.

While results from the 16S rRNA clone library analysis did not provide a clear biomarker for any of the commercially available bioaugmentation cultures, qPCR analysis indicated that the functional reductase gene *vcrA* was not present at NAVWPNSTA Site 70, but was present in high concentrations in bioaugmentation cultures. In order to determine if there were significant differences between the *vcrA* gene sequences present within the bioaugmentation cultures, clone libraries were constructed using *vcrA*-specific PCR primers. The NAVWPNSTA Site 70 sample did not amplify, confirming that the *vcrA* gene was not detected using either the qPCR or PCR protocols described. The BCI bioaugmentation culture, however, did not amplify either. Therefore, only the Shaw SDC-9™ and KB-1™ cultures had clone libraries constructed for the *vcrA* gene. The *vcrA* clone library DNA data would have been used to design a biomarker if the standard qPCR analysis for *vcrA* was not sufficient.

5.5 DESIGN AND LAYOUT OF TECHNOLOGY COMPONENTS

The demonstration area was designed to include two independent cells, one utilizing a recirculation system (active cell), and one relying on passive distribution of the introduced culture. The primary technology components of this demonstration included groundwater wells (injection, extraction, and monitoring wells), a gravity fed electron donor delivery system, a groundwater recirculation system, and a bacteria injection system.

5.5.1 Well Layout and Cell Placement

Two treatment cells were installed at NAVWPNSTA Site 70, one for the passive distribution system and one for the active distribution system (Figure 5-1). The treatment cells were based on the following criteria:

- Both cells should be located within the source area or the high concentration area surrounding the source area (i.e., TCE concentrations greater than 1,000 ppb).
- The cells should be located such that hydraulic autonomy could be maintained between the passive and active cells; therefore the extraction wells in the active cell do not capture significant volumes of groundwater from the passive cell during the duration of the demonstration.
- The well layout within each cell must allow for meaningful results to be observed within the 12-month duration of Phase 3 bioaugmentation activities.
- Both cells should be oriented generally in the direction of groundwater flow

These criteria were met by the treatment cell layouts based on tracer test results and phased treatment cell construction, as described in Section 5.2

For the active treatment cell, the overall dimensions are 130 feet by 50 feet. A pair of extraction wells and a pair of injection wells were installed 105 feet apart, with the spacing between extraction wells and injection wells 25 feet and 20 feet, respectively. The final active cell well screened depth intervals and CMT sampling depths are shown in Table 5-1. During drilling, soil lithology was recorded based on the Unified Soil Classification system (ASTM-D 2488-93) for all boreholes. The soil boring / well construction logs for each well are provided in Appendix E. All wells, including CMT wells, were developed to comply with California Division of Water Resources Water well standards. A summary of the development of each well is also provided in Appendix E.

For the passive cell, the overall dimensions are 100 feet by 35 feet (Figure 5-1). Within this area, three injection wells are located along the axis of the treatment cell at a spacing of 35-45 feet. A total of six standard monitoring wells are located in the passive treatment cell. Three of these wells are located along the axis of the treatment cell and are spaced between 12 and 17 feet from the injection wells. The other three monitoring wells are located just off-axis, at a distance of about 7 to 9 feet from each of the three injection wells. The passive cell also has a transect of three CMT wells placed halfway between the first and second injection wells. The CMT wells are spaced approximately 17.5 feet laterally and were completed at three discrete sampling depths based on observed field conditions. Many of the proposed well locations were moved because of above ground and utility obstructions. The final passive cell screened depth intervals are provided in Table 5-1.

5.5.2 Standard Well Installation

Four different types of wells were installed for this demonstration: injection wells, extraction wells, Solinst® CMT monitoring wells, and standard monitoring wells. Except for CMT wells, all wells were completed with approximately 20 feet of 4-inch diameter schedule 40 PVC, wire wrapped 0.05 slot screen, and 4-inch schedule 40 PVC riser pipe installed from the top of screen approximately to ground surface. One foot of appropriately sized silica sand filter pack was added to the annular space beneath the bottom of the well. Well installation details are provided in Table 5-1 and well construction diagrams in Appendix E. The annular space surrounding the screen was backfilled with the silica sand filter pack to a depth of approximately 3 feet above the well screen and capped with a bentonite seal to at least 2 feet bgs. The remainder of the annular space was filled with concrete to ground surface and if necessary, widened into a 24-inch by 24-inch concrete pad at the surface (if the surface was not already concrete). All wells were flush mounted with bolted manhole covers and locking caps.

5.5.3 CMT Monitoring Well Installation

Three CMT monitoring wells were installed in each treatment cell as shown in Figure 5-1. The wells were aligned perpendicular to flow in each cell to evaluate three-dimensional transport. The CMT wells are 1.7-inch diameter and each has a minimum of four sampling ports as detailed in Table 5-1. Well construction diagrams for CMT wells are provided in Appendix E.

5.5.4 Passive Cell Electron Donor Distribution System

A gravity-fed electron donor distribution system was constructed to deliver a sodium lactate (electron donor) solution to all three of the passive cell injection wells simultaneously during discrete injection events. A process flow diagram is provided as Figure 5-2.

Make-up water for the passive cell injections was from a potable water source available onsite. The potable water was fed through a proportional flow mixer, which delivers lactate to the injection line at a concentration that is in proportion to the water flow rate.

The diluted lactate solution was transferred to a manifold capable of injecting into all three passive cell wells simultaneously. Each line of the manifold included a metered valve with a totalizer, and the manifold itself was mounted on plywood or similar board. Reinforced flex hose was used to convey the dilute lactate solution to the injection wells. These hoses were lowered in the well and placed near the middle of the well screen, and injections were performed under gravity flow (i.e., not under pressure).

5.5.5 Active Cell Recirculation System

For the active cell, a recirculation system was constructed to extract and re-inject groundwater continually (i.e., 24 hours per day, 7 days per week) across an area of approximately 130 feet. The system was designed to be capable of pumping total groundwater flows in the range of 0.5 – 5 gallons per minute (gpm) from each of two extraction wells (1-10 gpm total). To periodically pulse lactate into the recirculation line, a second proportional feed mixer was installed for use only when lactate injections were required. Instrumentation and controls were provided such that the system can run without an operator onsite, except for periodic inspections and maintenance. Below is a brief description of the operating requirements and parameters for the active treatment cell. A process flow and instrumentation diagram is provided as Figure 5-3.

The system was designed to extract groundwater from each of the two extraction wells using environmental duty submersible pumps and pump it into a double walled surge tank. The pumps were controlled by two float switches. The high level switch LSH-100 initiates the pumps' run operation (Figure 5-3). When the groundwater level drops below LSL-100, the pumps would stop. The pumps' operation was interlocked with Hi-Hi level switch LSHH-200 in the surge tank. If the Hi-Hi level was reached in the surge tank the extraction pumps stopped. The level switch locations in the extraction well were modified after low groundwater levels caused the pumps to cycle during a period of low precipitation.

Extracted groundwater was conveyed to the treatment skid, which consisted of the surge tank, transfer pump, manifold, and electronics. Each extraction well was plumbed independently back to the treatment skid where they were combined prior to discharge into the surge tank. Each leg contained a check valve to prevent extracted groundwater from flowing back into the well. Each leg also included a pressure gauge, a totalizing flow meter and a gate valve.

The surge tank included two level switches to control the injection pump. Level switch LSH-200 initiated the pumps' run operation. When the water level dropped to below LSL-200 the pumps would stop. The pump operation was interlocked with the Hi-Hi level switch LSHH-300 located

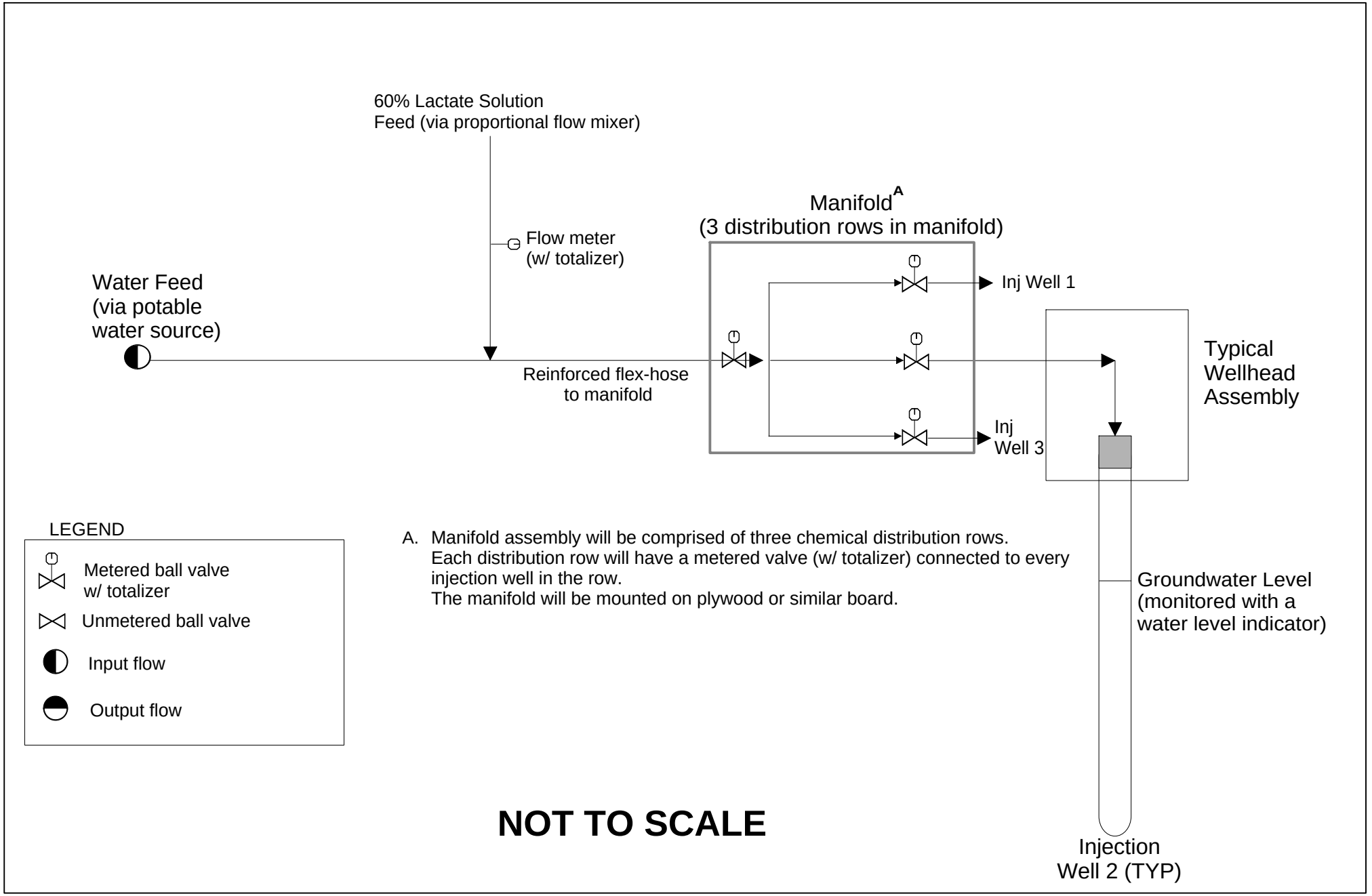
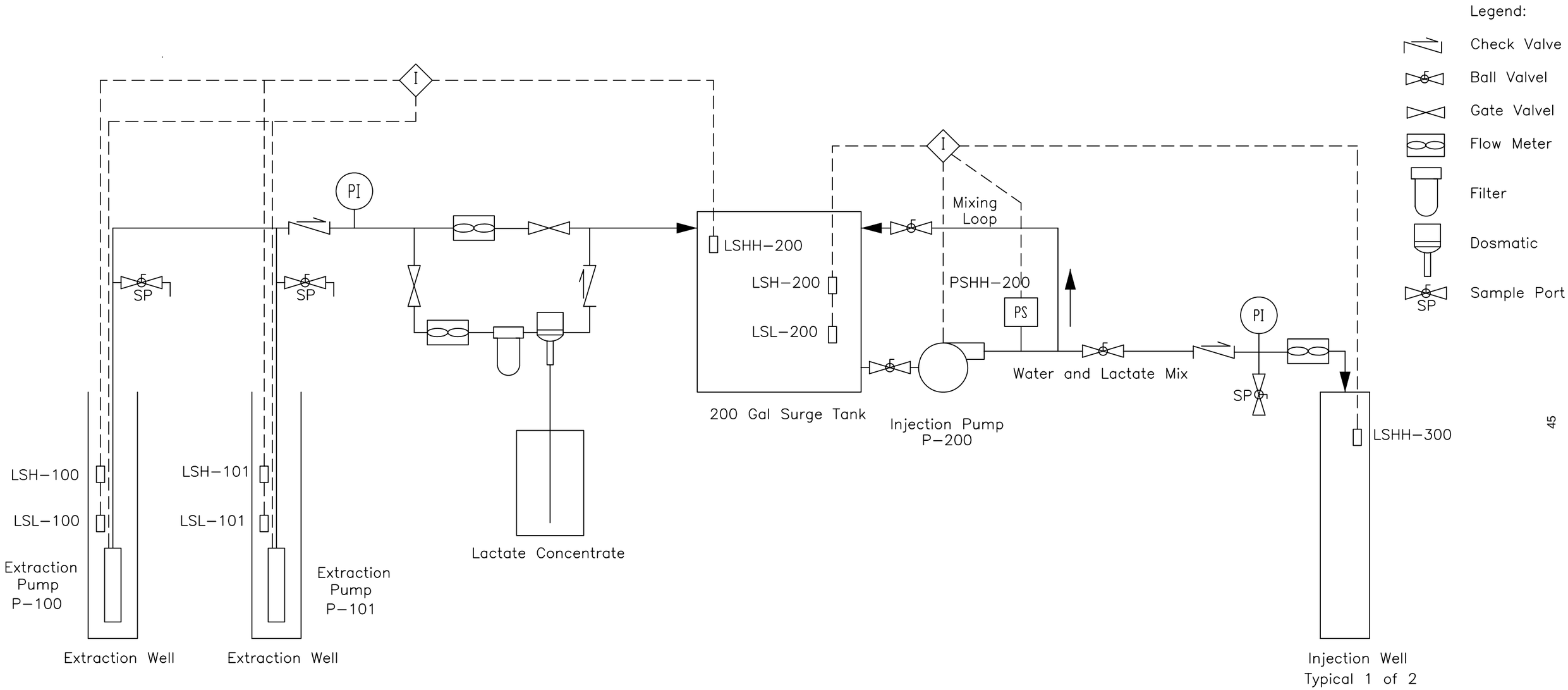


FIGURE 5-2
PROCESS FLOW DIAGRAM - SUBSTRATE DELIVERY
FINAL REPORT
SEAL BEACH NAVAL WEAPONS STATION, SEAL BEACH, CA



45

REV.	DATE	DESCRIPTION	BY	CKD.	APP.

DESIGNED BY: DAG
DRAWN BY: DAG
CHECKED BY:
APPROVED BY:
DATE:

Prepared By
CDM Camp Dresser & McKee Inc.
consulting engineering construction operations

Navy Bio–Augmentation Site

Seal Beach, CA

Figure 5-3
Active Cell Test Area
Injection System P&ID

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in the injection well. When the Hi-Hi level was reached in injection well the injection pumps would stop. The pump was also interlocked with the Hi-Hi pressure switch located on the discharge. The Hi-Hi pressure alarm would be a result of either clogging of the discharge totalizing meter or the well screen of the injection well. The Hi-Hi pressure alarm was never tripped during operation of the recirculation system.

The discharge was plumbed to allow recirculation of the water and donor mixture prior to injection if needed. The discharge line was also equipped with a check valve, pressure gauge, and totalizing flow meter.

All processes were controlled by an Idec brand Programmable Logic Controller (PLC). The PLC allowed for field modifications of the process without the need to rewire the control panel. A wireless telemetry unit was later added to notify the operator of any operational alarms.

Extracted groundwater from the 275-gallon surge tank was pumped to the injection wells during normal operations. During an electron donor injection event the extracted groundwater was diverted to a standalone proportional inline mixer, where lactate was added. The lactate-amended water was then conveyed to the injection wells.

The equipment area was located between the extraction and injection wells based on site constraints. The signal cable between the equipment area and the piezometer level switches was placed in a conduit. Double walled piping was used to convey extracted water to the lactate injection system and to the injection wells.

Submersible pumps were installed 6 inches from the bottom of each extraction well, and piping was installed between the extraction wells and injection wells in the recirculation cell. The extraction wells each transfer to one central vault, which housed all of the controls, sampling ports, flow meters, and check valves for both extraction wells. Piping was then run from the vault to the reinjection wells. The vault, all transfer piping and wiring was installed below ground to minimize impacts to normal operations at the site. Because of low traffic in the area, a shallow (6-inch) trench was dug to install the piping and wiring within a PVC conduit. Once the piping was installed, the trench was covered with new asphalt. All transfer piping between the extraction wells and the injection wells was constructed with high density polyethylene (HDPE), double-lined piping.

5.5.6 Bacteria Distribution System

The bacteria distribution system was designed to inject the desired bacteria directly into each injection well at the wellhead. The bacteria were provided in 20-L pressurized vessels. Pressurized argon was used to evacuate the headspace in each well and to fill the vessel as the bacteria were removed. The well headspace was then evacuated by lowering Teflon tubing to just above the water table and injecting a comparative volume of argon into the well.

Immediately following evacuation, 20 L of bacteria was injected into the subsurface using Teflon tubing. The tubing was installed approximately to the center of the well screen. Figure 5-4 shows a typical bacterial injection setup.

Figure 5-4
BACTERIA INJECTION SYSTEM EXAMPLE
ER-0513 FINAL REPORT
SEAL BEACH NAVAL WEAPONS STATION, SEAL BEACH, CA

CDM

5.6 FIELD TESTING

Field activities during this demonstration included system startup, pre-conditioning (Phase 2), Bioaugmentation (Phase 3), and system shut down. Additional activities included temporary shutdown of the recirculation system and modification of lactate injections. This section includes details of these activities performed during the demonstration.

5.6.1 System Start-up

Once the wells for the active cell were installed and the active cell recirculation system itself was constructed and installed, the recirculation system was tested in March and April 2008. As described above, the system operated by extracting groundwater from wells AEW-1 and AEW-2 into a 275-gallon surge tank; the surge tank water was reinjected into AIW-1 and AIW-2, which is a distance of 100 feet upgradient from the extraction wells (refer to Figure 5-1 for well locations). Once the system was functional, it was operated for several days, and water levels were measured in active cell monitoring wells, and in the two existing passive cell monitoring wells, in order to determine the groundwater flow direction in the area of the proposed passive cell wells. Synoptic water level data were collected in several wells using transducers, and in other wells by taking water levels using a water level meter.

Prior to installing the passive cell wells, whose locations were being determined in part based on potential effects from the recirculation system, one round of lactate injections was performed in the active cell in April 2008. The injections were performed by "pulsing" the lactate into the recirculation line to the two injection wells. Approximately 950 gallons was injected at a weight concentration of 2.5 percent (i.e., 25,000 mg/L). The full lactate injection summary is provided in Table 5-2. During startup the observed flow rates from each of the extraction wells were less than anticipated (approximately 0.7-0.8 gpm), and because of this, the concentration of lactate was increased to 2.5 percent from 1 percent during injection.

5.6.2 Pre-conditioning

Once the system was determined to be performing as designed and the additional passive cell wells were installed, "pre-conditioning" of the treatment cells was performed, consisting of lactate injections sufficient to remove sulfate and create strongly reducing conditions. At each well, lactate was injected every 4 weeks into the passive injection wells and quarterly into active injection wells. Pre-conditioning started much sooner in the active treatment cell, though it was completed in January 2009 for both cells. Approximately 50 gallons of sodium lactate stock solution was injected into each cell during each injection event. The lactate injection summary is provided in Table 5-2. A more detailed injection summary is provided as Appendix F.

Groundwater sampling was performed during pre-conditioning to monitor the subsurface conditions prior to initiating bioaugmentation. Groundwater samples were collected according to the sampling schedules shown in Section 5.7.

Table 5-2. Lactate Injection Summary

Well ID	Injection Date Range	Volume Water Injected (gallons)	Volume 60% Sodium Lactate Injected (gallons)	Sodium Lactate Conc. (%)	Volume Lactate Injected [1] (gallons)	Lactate Injection Conc. (%)	Total Injection Time (Hours)	Average Lactate Injection Flowrate (gpm)
PASSIVE CELL								
Pre-Conditioning Totals (Phase 2)								
PIW-1	8/7/08-1/12/09	4,011	67	1.7%	32	0.8%	64.6	1.0
PIW-2	8/7/08-1/12/09	4,156	67	1.6%	32	0.8%	59.5	1.2
PIW-3	8/7/08-1/12/09	4,151	67	1.6%	32	0.8%	59.5	1.2
TOTAL	**8/7/08-1/12/09**	**12,319**	**201**	**1.6%**	**96**	**0.8%**	**64.6**	**3.2**
Post-Bioaugmentation Totals (Phase 3)								
PIW-1	1/13/09-10/31/09	8,481	143	1.7%	69	0.8%	143.4	1.0
PIW-2	1/13/09-10/31/09	8,519	143	1.7%	69	0.8%	143.4	1.0
PIW-3	1/13/09-10/31/09	8,549	144	1.7%	69	0.8%	143.4	1.0
TOTAL	**1/13/09-10/31/09**	**25,549**	**430**	**1.7%**	**206**	**0.8%**	**143.4**	**3.0**
OVERALL Totals								
PIW-1	8/7/08-10/31/09	12,492	209	1.7%	101	0.8%	208.0	1.0
PIW-2	8/7/08-10/31/09	12,675	211	1.7%	101	0.8%	202.9	1.0
PIW-3	8/7/08-10/31/09	12,701	211	1.7%	101	0.8%	202.9	1.0
TOTAL	**8/7/08-10/31/09**	**37,868**	**631**	**1.7%**	**303**	**0.8%**	**208.0**	**3.0**
ACTIVE CELL								
Pre-Conditioning Totals (Phase 2)								
AIW-1	4/23/08-1/12/09	2,343	96	4.1%	46	2.0%	60.5	0.6
AIW-2	4/23/08-1/12/09	2,507	101	4.0%	49	1.9%	60.5	0.7
TOTAL	**4/23/08-1/12/09**	**4,850**	**198**	**4.1%**	**95**	**2.0%**	**60.5**	**1.3**
Post-Bioaugmentation Totals (Phase 3)								
AIW-1	1/13/09-10/31/09	15,389	547	3.6%	262	1.7%	312.9	0.8
AIW-2	1/13/09-10/31/09	14,375	504	3.5%	242	1.7%	312.9	0.8
TOTAL	**1/13/09-10/31/09**	**29,764**	**1,061**	**3.6%**	**504**	**1.7%**	**312.9**	**1.6**
OVERALL Totals								
AIW-1	4/23/08-10/31/09	17,732	643	3.6%	309	1.7%	373.4	0.8
AIW-2	4/23/08-10/31/09	16,882	605	3.6%	290	1.7%	373.4	0.8
TOTAL	**4/23/08-10/31/09**	**34,614**	**1,258**	**3.6%**	**599**	**1.7%**	**433.9**	**1.3**

[1] 60% Sodium Lactate contains approximately 48% bioavailable lactate.

5.6.3 Temporary System Shutdown

The recirculation system was shut down temporarily to add additional controls including a secondary overflow tank and an autodialer in late 2008. Therefore, the recirculation system was not operating between October 2008 and January 2009. The system was re-started approximately one week before beginning Phase 3 – Bioaugmentation.

5.6.4 Bioaugmentation

Once the pre-conditioning phase was completed, both the passive and active cells were inoculated with the SDC-9™ *DHC* culture in January 2009. The inoculation was performed by first injecting 90 percent of the monthly electron donor volume into each cell, followed by inoculation, and finally by "flushing" the wells with anoxic water.

To do this, lactate injections into the passive and active cells were performed the week of January 5, 2009. In the passive cell, approximately 953 gallons of 1 percent lactate solution were injected into wells PIW-1, PIW-2, and PIW-3.

A lactate injection was also performed into the active cell the week of January 5, 2009. Approximately 2,975 gallons of 1 percent to 1.5 percent lactate was injected into wells AIW-1 and AIW-2 by feeding lactate into the recirculation water.

Following the initial lactate injections, each cell was inoculated with approximately 100 L of SDC-9™. The inoculation was performed by injecting proportional amounts of culture into each injection well (50 L per well in active cell, 33 L per well in passive cell) with argon as a carrier gas to ensure the culture did not come in contact with air.

Once the wells were inoculated, the final 10 percent of lactate-amended water for the injection was added to each injection well (i.e., 100 gallons per well). This lactate solution was mixed approximately 72 hours before injecting to ensure that the water was anoxic.

5.6.4.1 Lactate Injection Modifications

Following the bioaugmentation, lactate injections were continued for 8 months. However, the injection strategy was modified in the active cell. Because carbon distribution was less than anticipated in the active cell, the pulsing strategy was modified to weekly from monthly. Although the frequency of injections was increased, the volume was decreased to approximately 12.5 gallons of stock lactate per event such that the monthly lactate mass injected did not change.

In June 2009, the active cell lactate injection strategy was modified again based on continued low carbon distribution throughout the active cell. The lactate concentration during each weekly injection was increased such that 50 gallons of stock sodium lactate were injected per event.

5.6.4.2 Groundwater Sampling

Groundwater sampling was performed following bioaugmentation to monitor the contaminant destruction, electron donor distribution, and bacterial distribution and activity. Groundwater samples were collected according to the sampling schedule shown in Section 5.7.

5.6.5 System Shut-down

In October 2009, the recirculation system was shut down. Once it was determined in March 2010 that no additional data would be collected, the system was decommissioned in April 2010, and all equipment was removed from the site.

5.7 SAMPLING METHODS

Groundwater sampling was performed in each of the three phases of the demonstration to collect data sets that would achieve the project objectives. Phase 1 included one round of baseline sampling, and Phase 2 included three rounds of sampling. Following bioaugmentation, eight rounds of sampling were performed.

5.7.1 Sampling Summary

Samples were collected as shown in Table 5-3 during the demonstration. All injection wells and monitoring wells (including CMT wells) were sampled in the passive cell during each event, and the combined effluent from the two extraction wells and all monitoring wells (including CMT wells) were sampled in the active cell during each event. Not all analyses were performed during each event, as specified in Table 5-3. Not all screened intervals in the CMT wells were sampled during each event by design. Additionally, because the depth to water varied during the course of the demonstration, the amount of intervals sampled had to be modified if certain intervals were dry. A detailed summary of the samples collected is provided in Appendix G.

5.7.2 Analytical Methods

Analytical techniques for this demonstration included standard EPA methods for VOCs, ethene/ethane/methane, anions, COD, and alkalinity, as well as accepted field measurements using water quality instruments and field test kits. Two innovative analytical techniques for which no standard EPA methods exist are included in this demonstration, both of which are important for assessing the demonstration's performance. A summary of the analytical methods used is provided in Table 5-4.

The two innovative analytical techniques used during this demonstration were qPCR and carbon stable isotope analysis (CSIA). As discussed above, these techniques do not have standard EPA methods, although the methods have been published. The actual analytical method is published for qPCR by Rahm et al. (2006) and for CSIA by Song et al. (2002).

qPCR

The most crucial of these methods is qPCR, which was used to track the growth and distribution of the introduced bacteria. Initial detections of bacteria at a given well were used to calculate bacterial transport times, which were used to infer whether differences in the bioaugmentation strategies impacted distribution.

Table 5-3. Monitoring Summary

Sampling Round	Sampling Date	Number Recirculation Cell Well Samples			Number Passive Cell Well Samples			Total	Number of QA/QC samples[2]
		Extraction	Monitoring	CMT[1]	Injection	Monitoring	CMT[1]		
Baseline Sampling **(C)**	April-08	2	3	9	3	6	9	**32**	**4**
Pre-conditioning – Month 1	May-08	2	3	3	3	6	3	**20**	**2**
Pre-conditioning – Month 2	September-08	2	3	3	3	6	3	**20**	**2**
Pre-conditioning – Month 3 **(C)**	November-08	2	3	9	3	6	9	**32**	**4**
Bioaugmentation sampling – Month 4	January-09	2	3	3	3	6	3	**20**	**2**
Bioaugmentation sampling – Month 5 **(C)**	February-09	2	3	3	3	6	3	**20**	**2**
Bioaugmentation sampling – Month 6	March-09	2	3	3	3	6	3	**20**	**2**
Bioaugmentation sampling – Month 7 **(C)**	April-09	2	3	9	3	6	9	**32**	**4**
Bioaugmentation sampling – Month 8	May-09	2	3	3	3	6	3	**20**	**2**
Bioaugmentation sampling – Month 9	June-09	2	3	3	3	6	3	**20**	**2**
Bioaugmentation sampling – Month 10 **(C)**	October-09	2	3	9	3	6	9	**32**	**4**
Bioaugmentation sampling – Month 13 **(C)**	December-07	2	3	3	3	6	3	**20**	**2**
Bioaugmentation sampling – Month 16 **(C)**	N/S	**Month 16 Sampling Event not required based on meeting demonstration objectives.**							
Totals								**320**	**36**

All samples were analyzed for the following parameters (analysis details shown in Table 5-4):

- *Field parameters*
  - Conductivity, pH, Temperature, Dissolved Oxygen, Oxidation Reduction Potential, Turbidity, Ferrous iron, and iodide tracer
- *Lab parameters (Method ID)*
  - VOCs (8260B), Dissolved Gases - Methane, Ethane, and Ethene (RSK 175), Anions (353.2), Alkalinity (310.1), DNA Analysis (qPCR), Chemical Oxygen Demand - COD (410.4)

(C) All samples collected during the Baseline, Month 3, Month 5, Month 7, Month 10, Month 13, and Month 16 sampling periods were analyzed for stable carbon isotopes.

1 Only one depth sampled from each CMT well during months 1, 2, 4, 5, 6, 8, 9 and 13. Up to 3 depths sampled in other sampling periods, depending on observed water levels.

2 Approximately 10% of all samples were collected for QA/QC during the monitoring period.

Table 5-4. Sample Collection and Analysis Summary

Analytes	Sample container size and type	Preservative	Analytical Method	Holding time	Comments
Field laboratory analyses [priority]					
Ferrous Iron [1]	One 125-mL HDPE	4°C	Hach Method 8146	30 minutes	Must be analyzed immediately; no headspace
Tracer - Iodide [2]	One 125-mL HDPE	4°C	Ion specific Electrode	4 hrs	
Off-site laboratory analyses					
VOCs	Two glass 40-mL VOA vials	4ºC	SW-846 8260B	7 days	No headspace
DNA Sequencing	One 1-L HDPE	4ºC	qPCR	3 days	No headspace
Stable Carbon Isotopes	One 1-L HDPE	4ºC	GC-IRMS	7 days	No headspace
Ethene/ethane/methane	Three glass 40-mL VOA vials	4ºC	RSK-175 (or equivalent)	7 days	No headspace
Chloride	One 250-mL HDPE	4ºC	EPA 325.3	28 days	
Chemical Oxygen Demand	One 50-mL HDPE	H_2SO_4 / 4ºC	EPA 410.4	28 days	
Alkalinity	One 250-mL HDPE	4ºC	EPA 310.1	14 days	
Nitrate	One 250-mL HDPE	4ºC	EPA 300.0	48 hours	See below
Nitrite/Nitrate	One 250-ml HDPE	H_2SO_4 / 4ºC	EPA 353.2	14 days	Added because 48-hour hold time not always achievable for Nitrate analysis
Sulfate	One 250-mL HDPE	4ºC	EPA 375.4	28 days	

qPCR = quantitative polymerase chain reduction
HDPE = high-density polyethylene
VOA = volatile-organic analysis

The DNA extractions and qPCR analyses were performed by North Wind, Inc. because of their specialized expertise in clone library development, DNA sequencing, and qPCR method development.

CSIA

The second innovative analytical technique was CSIA for TCE, *cis*-1,2-DCE, VC, and ethene. Following the analysis, stable carbon isotope ratios for each compound were determined to evaluate degradation patterns and the extent of dechlorination of parent compounds. Stable carbon isotope ratios are described in terms of $\delta^{13}C$, which is defined by the following equation:

$$\delta^{13}C = ((R_{sample}/R_{standard}) - 1) \times 1{,}000$$

where:

δ	=	delta notation of stable isotope ratio
^{13}C	=	carbon-13
R	=	concentration of carbon-13/concentration of carbon-12

Thus, if the sample has a lower ratio of carbon-13 to carbon-12 than the ratio of the reference standard, $\delta^{13}C$ is negative. If the sample has a higher ratio, then $\delta^{13}C$ is positive. Stronger molecular bonds are formed by carbon-13 than by carbon-12. When dechlorination starts, the weaker-bonded carbon-12 isotopes tend to be transformed more quickly, resulting in the enrichment of carbon-13 in the residual reactant (e.g., cis-1,2-DCE that is being transformed to VC). This causes $\delta^{13}C$ to increase for *cis*-1,2-DCE. On the other hand, the amount of carbon-12 in the product (in this case, VC and ethene) is initially higher, causing $\delta^{13}C$ to be more negative. However, if a finite amount of reactant is present and the reaction proceeds to completion, then $\delta^{13}C$ of the product(s) will equal that of the initial reactant (Song et. al, 2002). In other words, when dechlorination starts, the $\delta^{13}C$ of the newly formed vinyl chloride and ethene will initially be much "lighter" (more negative) than baseline samples of *cis*-1,2-DCE (because of a higher amount of carbon-12 in the newly formed compounds than in the original *cis*-1,2-DCE). The *cis*-1,2-DCE's $\delta^{13}C$ will, in turn, become "heavier" (less negative) than baseline (because of a higher amount of carbon-13 than carbon-12 in the remaining *cis*-1,2-DCE) as it is dechlorinated. As the *cis*-1,2-DCE is completely dechlorinated, the $\delta^{13}C$ in the degradation products will approach and eventually equal that of the original *cis*-1,2-DCE.

The CSIA was performed by Lawrence Berkeley National Laboratory (LBL). The Center for Isotope Geochemistry stable isotope laboratory at LBL conducts basic and applied geochemical research using the isotope ratios of light elements including hydrogen, carbon, nitrogen, oxygen and chlorine. Results are included in Appendix H for the active cell and Appendix I for the passive cell.

Field Analyses

Field analyses for ferrous iron were performed as per the test kit manufacturer's instructions. Field analyses for DO, ORP, temperature, pH, and specific conductivity were performed as per the water quality meter manufacturer's instructions. Analysis for iodide tracers was performed per the ion specific electrode manufacturer's instructions.

5.7.3 Quality Control

Laboratory quality assurance (QA) for the onsite field analyses included analysis of blanks and duplicates. Offsite laboratory quality assurance requirements were defined in the laboratory SOW. Frequencies for QA analyses are specified in Table 5-5. Further details are provided in Appendix G, which addresses the appropriate sections of the Quality Assurance Project Plan for this demonstration. Also included in Appendix G is a description of the calibration procedures performed for all equipment not operated by a contract laboratory. For all equipment used outside the contract laboratory, calibration procedures were performed as per the manufacturer guidelines. Sample documentation procedures are also detailed in Appendix G.

All data, checklists, photographs, and calibration logs generated during the demonstration were included as part of the project file. These data and reports will be maintained by CDM.

Table 5-5. Field QA frequency for Groundwater Monitoring

Sample Type	Frequency	Comments
Field Duplicate	1 per 20 samples[a]	All samples
Field blank	1 per 20 samples[a]	All samples
Trip blank	1 per sample cooler	For off-site VOCs and ethene/ethane/methane samples only.

a: 1 sample for all analytes per day if number of monitoring locations is <20.

5.7.4 Decontamination Procedures

Any residuals that were generated during drilling and during the technology demonstration were handled and disposed in an appropriate manner. Residuals generated from this work included water during drilling, well development, and equipment decontamination; purge water from sampling; drill cuttings; field test kit wastes; sampling equipment decontamination wastes; and personal protective equipment (PPE).

Water generated during the demonstration was stored temporarily in a storage tank and then sent to an appropriate disposal facility for disposal. Soil generated during well installation was stored in a covered bin onsite.

All solid waste and RCRA waste was disposed offsite. The Generator EPA ID number for this site is CA0170024491.

5.8 SAMPLING RESULTS

This section summarizes the sampling results from the activities specified in Section 5.6. Specifically, an analysis of the concentration trends for five main parameters is provided in this section. In order for complete reductive dechlorination of TCE to ethene to occur biologically, electron donor must be adequately distributed, redox conditions must be sufficiently reducing, pH should be in the appropriate range, and appropriate microbial populations must be present and active. The performance of the active and passive cells was therefore evaluated based on the success of electron donor injections, extent of electron donor distribution, changes in redox

conditions, extent and rate of dechlorination, and changes in the microbial population within the aquifer of the active and passive cells.

5.8.1 Active Cell

Trends for the five parameters of interest in the active cell are presented in this section.

5.8.1.1 Electron Donor Distribution

COD was measured to indicate the amount of available electron donor in the groundwater. COD is an important metric, as it represents the carbon and energy available to dechlorinating bacteria. Complete COD results for the active cell are included in Table H-1 and figures showing the key COD concentration trends are presented in Appendix H.

The baseline sampling event (April 2008) showed COD concentrations ranging between 28 and 60 mg/L in active cell wells. During the pre-conditioning phase (April 2008 to January 2009) when quarterly pulsed electron donor injections (1,000 gallons of 2 percent (v/v) of sodium lactate solution) were performed, COD concentrations were observed to increase slightly (i.e., near 2X background concentrations) only at wells AMW-2 (78 mg/L in September 2008) and AMW-4 (Z1) (120 mg/L in May 2008). The concentrations at all other wells and zones remained near background. The quarterly injections were able to achieve some increase in COD concentrations compared to baseline and the electron donor distribution was observed approximately 36 feet downgradient (well AMW-4) of the injection wells within the active cell.

To achieve better electron donor distribution and increase the COD concentrations within the active cell, the injection strategy was modified to include weekly electron donor injections with approximately 750 gallons of 1 percent (wt/wt) sodium lactate solution between January 26 and June 9, 2009. During this period, a slight increase in COD concentrations near 2X background was observed at the monitoring wells (AMW-4 (Z1) - 85 mg/L in February 2009, AMW-5 (Z1 [83 mg/L in June 2009] and Z2 [70 mg/L in April 2009]) and the upgradient well (AMW-1 – 120 mg/L in February 2009). Only well AMW-2 showed COD concentrations of a few hundred mg/L, which peaked in January 2009 (580 mg/L), but then decreased and was observed near background by May 2009 (Figure 5-5). The concentrations at all other wells and zones remained near background. The donor distribution was still approximately 36 feet downgradient but now included well AMW-5 and effects were also observed approximately 25 feet upgradient (AMW-1) of the injection wells within the active cell.

To further improve electron donor distribution and increase the COD concentrations within the active cell, the injection strategy was modified again to include weekly electron donor injections using approximately 1,000 gallons of 3 percent sodium lactate solution between June 10 and October 2, 2009. Elevated COD concentrations in the range of a few hundred mg/L were observed in October 2009 at a number of monitoring wells including AMW-2 (400 mg/L), AMW-3 (Z2) (540 mg/L), AMW-4 (Z1 [420 mg/L]), AMW-5 (Z2) (350 mg/L), and the upgradient well, AMW-1 (180 mg/L). The donor distribution was now greater than 36 feet downgradient of the injection wells and also included wells AMW-3 (Z2) and AMW-4 (Z2) but still failed to reach well AMW-6 located approximately 72 feet downgradient of the injection well. Continued effects of donor distribution were also observed approximately 25 feet upgradient of the injection well within the active cell. The majority of the COD increases were

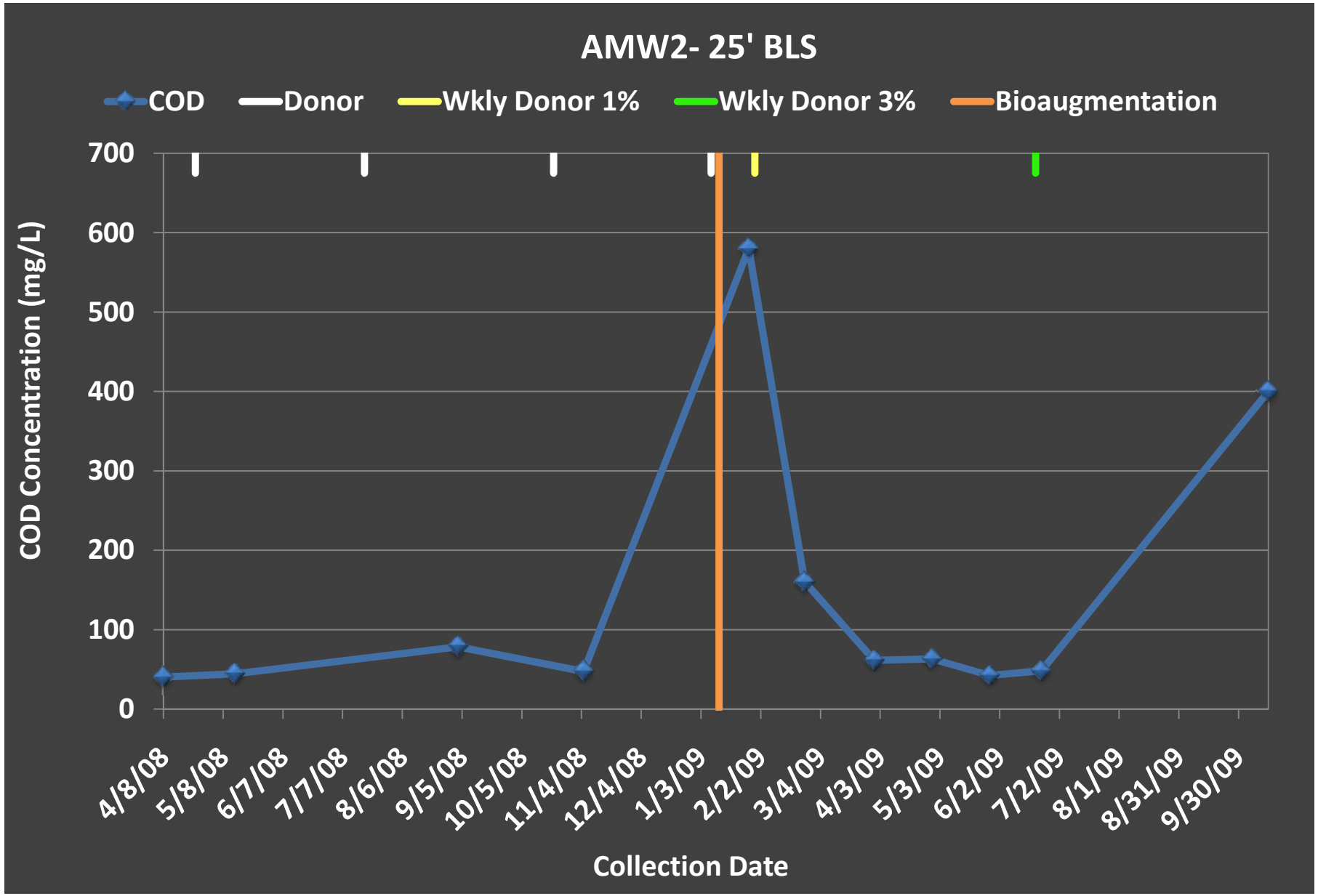


Figure 5-5
COD CONCENTRATION TREND, AMW-2
NAVWPNSTA SEAL BEACH SITE 70
SEAL BEACH, CALIFORNIA

Recirculation system was shut off between 9/2/2008 and 1/6/2009.

observed in zones 1 and 2 of the CMT wells. It should be noted that Zone 3 of the CMT well AMW-5 was never sampled during the pilot test due to a lack of water at that location. Furthest downgradient wells AMW-6 and AEW did not show elevated COD concentrations throughout the pilot test, indicating that donor was not distributed at these wells.

5.8.1.2 Redox conditions

Redox conditions are frequently monitored by measuring the ORP. It is a simple indicator of redox conditions and can be easily measured on site during the field activities. However, it is not the most accurate parameter in assessing the actual redox conditions, and if considered alone can sometimes be misleading. Thus, it is also required to monitor concentrations of certain inorganic electron acceptors in addition to ORP to assess the redox conditions at a site accurately. ORP measurements and concentrations of inorganic electron acceptors (DO, nitrate, ferrous iron, sulfate and methane) for the active cell are included in Table H-1 and figures showing the key changes in electron acceptors are presented in Appendix H.

ORP

ORP is measured in a flow-through cell during sampling. Generally, ORP measurements that are slightly positive indicate mildly reducing conditions. Reductive dechlorination is generally possible with ORP values less than approximately +50 millivolts (mV), but more negative ORP measurements (less than -100 mV) indicate strongly reducing conditions that are favorable for complete reductive dechlorination (EPA, 1998).

ORP values at all the active cell wells were mostly high and ranged from 73 mV to 443 mV during the baseline sampling event, with the exception of wells AMW-5 (Z1 [-83 mV] and Z2 [15 mV]). Following electron donor injections ORP values were reduced at all the active cell wells. As of October 2009 the ORP values were observed below 50 mV at all the active cell wells, and were observed below -100 mV at wells AMW-1, AMW-2, AMW-3 (Z2), AMW-4 (Z1 and Z2), and AMW-5 (Z1 and Z2). Overall, the ORP values at the monitoring wells were in the appropriate range for dechlorination and indicate establishment and sustenance of moderate to strongly reducing conditions within the active cell.

Electron Acceptors and Reduced Products

As discussed above, the aqueous concentrations of inorganic electron acceptors and their reduced products are a more reliable indicator of reducing conditions in the groundwater than ORP. The redox conditions typically progress from aerobic → nitrate reducing → iron reducing → sulfate reducing → methanogenic following addition of a sufficient supply of electron donor. Decreases in concentrations of DO, nitrate, and sulfate, and increases in ferrous iron and methane indicate that conditions are becoming favorable for dechlorination.

Dissolved Oxygen

Low DO concentrations are required for reductive dechlorination to occur; generally DO concentrations less than 0.5 mg/L are best for reductive dechlorination, whereas higher DO concentrations (generally greater than 1 mg/L) are harmful (EPA, 1998). DO was not a reliable redox indicator during this demonstration, likely because of equipment problems, and so it is not discussed here.

Nitrate Reduction

Nitrate concentrations of less than 1 mg/L are considered appropriate for dechlorination (EPA, 1998). The baseline sampling event showed nitrate concentrations less than 1 mg/L at all the active cell wells. The already low nitrate concentrations were reduced and observed near or below detection limit at all the active cell wells during the pilot test. Overall, the results indicate that nitrate reduction was not an important process within the active cell due to the lack of nitrate available.

Iron Reduction

Ferrous iron is the product of ferric iron reduction. Ferrous iron concentrations of near or greater than 1 mg/L are considered indicative of iron-reducing conditions that could support dechlorination (EPA, 1998). The baseline sampling event showed ferrous iron concentrations of less than 0.25 mg/L at all the active cell wells. Ferrous iron concentrations increased at all the active cell following donor distribution except wells AMW-6 and AEW. At well AMW-2 the ferrous iron concentration were near or above 3 mg/L between September 2008 and June 2009 but were reduced to below detection limit in October 2009. The blackish water observed during this sampling event indicates that the decrease in ferrous iron concentration may be due to the production of reduced iron sulfide minerals (ferrous iron reacts with sulfide, which is formed from sulfate reduction). This has been observed at sites where ferrous iron is not available in dissolved form under intrinsic conditions and sulfate is present in large amounts. As of October 2009, elevated ferrous iron concentrations of near or above 3 mg/L were observed at wells AMW-3 (Z2 and Z3), AMW-4 (Z1 and Z2), and AMW-5 (Z2). Increases in ferrous iron concentrations were also observed at wells AMW-3 (Z1) (February 2009) and AMW-4 (Z3) (April and June 2009), but the concentrations were not sustained. At the upgradient well AMW-1 the ferrous iron concentrations varied and depended on the donor distribution. As of October 2009 elevated ferrous iron concentration (above 3 mg/L) were observed at well AMW-1. Overall, the results indicate that iron reducing conditions were established at the wells in the upper portion of the active cell.

Sulfate Reduction

Optimal dechlorination rates are typically supported by sulfate concentrations of less than 20 mg/L (EPA 1998). However, as shown in Section 5.4, dechlorination can occur at sulfate concentrations higher than this at sites where initial sulfate is greater than 500-1,000 mg/L. Because of this, the more important indicator of appropriate redox conditions is downward trends in sulfate concentrations, which indicate that sulfate reduction is occurring.

Baseline sulfate concentrations were above 3,000 mg/L in all the active cell wells except well AEW. Near the injection wells, sulfate was above 7,000 mg/L; closer to extraction wells AEW the sulfate concentration was 1,600 mg/L. Following donor injections sulfate concentrations decreased considerably at all the wells in the upper portion of the active cell: AMW-1, AMW-2, and all three zones of CMT wells except well AMW-5 zones 1 and 3 (no data collected). As of October 2009 sulfate reductions in the range of 62 percent to 98 percent were achieved at wells AMW-2, AMW-3 (Z1 to Z3), AMW-4 (Z1 to Z3), and AMW-5 (Z2) depending on the extent of donor distribution. At the upgradient well AMW-1 the sulfate concentrations varied and depended on the donor distribution.

Compared to baseline, 57% removal of sulfate was observed at well AMW-1 in October 2009. Some increase in sulfate concentrations was observed at wells AMW-6 and AEW during the pilot test indicating the breakthrough of water from upgradient at these wells. Overall, the results indicate that sulfate reducing conditions were established at the wells in the upper portion of the active cell.

Methanogenesis

Methanogenesis, the production of methane from carbon dioxide, is the most favorable redox condition for complete dechlorination. Methanogenesis results in increased concentrations of methane. During the baseline sampling event, low methane concentrations (less than 0.15 mg/L) were observed at all the active cell wells. Methane concentrations remained near baseline (less than 0.15 mg/L) at the active cell wells throughout the operation of the pilot test indicating that strongly methanogenic conditions were not observed at any well within the active cell.

Redox Summary

Based on the results discussed in this section, it can be concluded that redox conditions shifted in accordance with the electron donor distribution, and as of October 2009, sulfate reducing to methanogenic conditions were established within the active cell except in the furthest downgradient locations, AMW-6 and the AEW wells. An example of redox conditions is included in Figure 5-6 for AMW-4 Zone 1.

5.8.1.3 VOC Concentrations

The concentrations of electron donor and redox conditions only indicate whether conditions are favorable for reductive dechlorination to progress at a site. The concentrations of chloroethenes and ethene need to be monitored as direct evidence. Complete results for VOC concentrations for the active cell are presented in Table H-1 and figures showing the key VOC concentration trends are presented in Appendix H.

Baseline conditions (April 2008) were characterized by high chloroethene concentrations observed at the active cell wells, primarily consisting of TCE concentrations ranging between 96 µg/L and 10,000 µg/L and DCE concentrations ranging between 5 µg/L and 660 µg/L. Exceptions were wells AMW-6, which exhibited a much higher TCE concentration of 140,000 µg/L, and AEW, which exhibited a DCE concentration of 1,900 µg/L. A low concentration of VC was detected only at well AEW (48 µg/L), whereas ethene was not detected at any of the active cell location during the baseline sampling event.

Following electron donor injections, an increase in TCE and total chloroethene concentrations was noted at all the wells sampled. This was likely caused by desorption and/or enhanced dissolution from a residual TCE source, and also due to the fact that TCE concentrations near the extraction well were higher than those near the injection wells at the start of recirculation. The concentrations of total chloroethenes increased by a factor ranging from nearly 4X at well AMW-2 to greater than 39X at well AMW-4 (Z2) in April 2009 when compared to the baseline concentrations.

During the pre-conditioning phase (April to November 2008), a dramatic increase in DCE concentrations ranging from 650 µg/L to 8,400 µg/L in November 2008 was observed at the

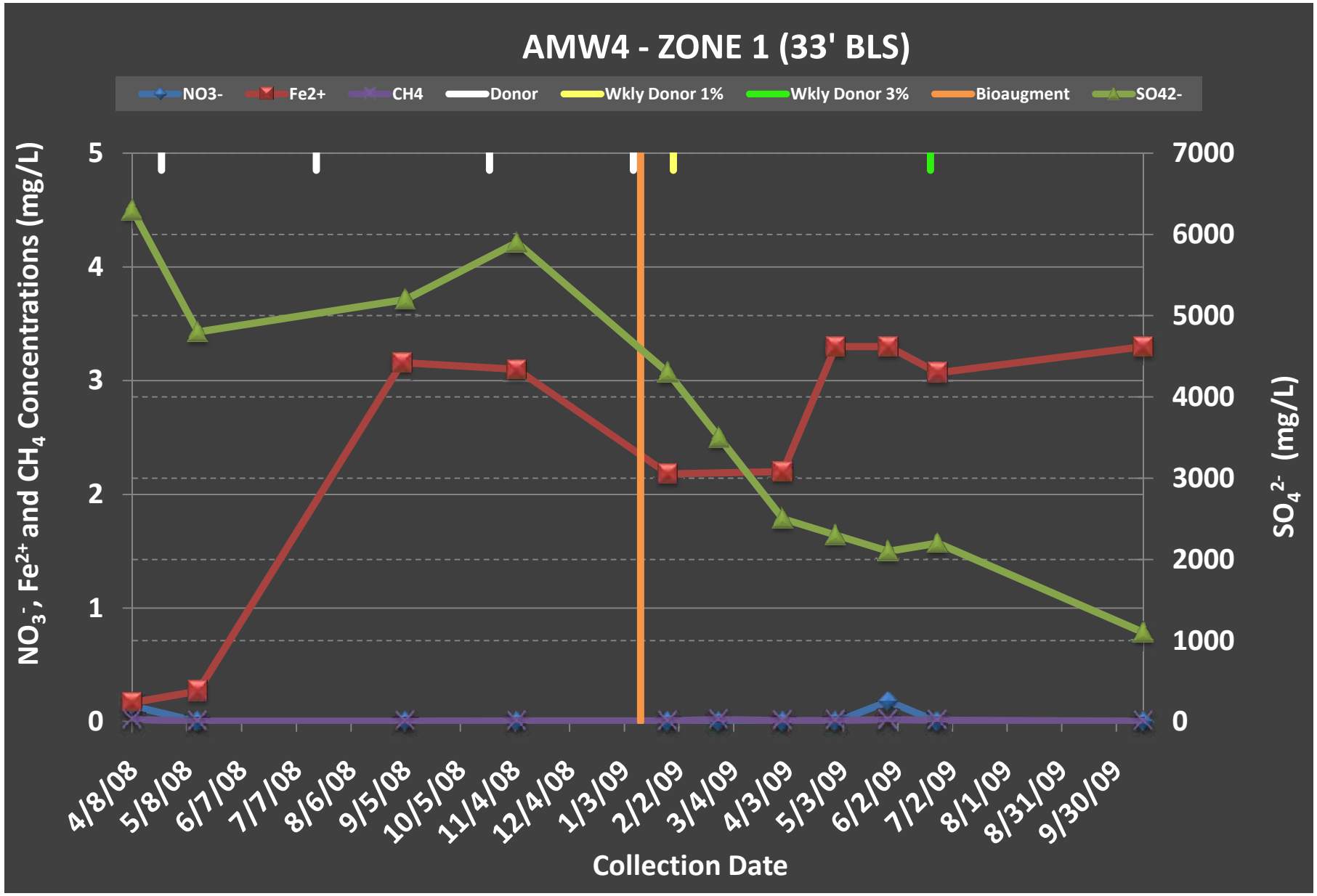


Figure 5-6
ELECTRON ACCEPTOR CONCENTRATION TREND, AMW-4 ZONE 1
NAVWPNSTA SEAL BEACH SITE 70
SEAL BEACH, CALIFORNIA

Recirculation system was shut off between 9/2/2008 and 1/6/2009.

wells located in the upper half of the active cell (AMW-1, AMW-2, AMW-3 (Z1 to Z3), AMW-4 (Z1 to Z3), and AMW-5 (Z1 to Z3). The increase in DCE concentrations indicated that degradation of the TCE was occurring. However, very little increase in VC concentration was observed during pre-conditioning, (detected at 9 µg/L to 35 µg/L at wells AMW-2, AMW-3 (Z1), AMW-4 (Z1), and AMW-5 (Z2)) and no ethene production was observed during the pre-conditioning phase. These results suggested the necessity for bioaugmentation for dechlorination to progress within the active cell.

Following bioaugmentation and the change to weekly lactate injections, further progress in dechlorination was observed rapidly in the upper half of the active cell with increases in removal of TCE and conversion largely to VC and some ethene. The highest ethene concentration of 200 µg/L was observed at well AMW-3 (Z1) during June 2009. Well AMW-5 (Z3) could only be monitored in April 2009 and the presence of large concentrations of DCE (>4200 µg/L) and some VC (170 µg/L) indicated that this well was also being impacted by the injections. At the upgradient well AMW-1, good progress in dechlorination was observed following donor injections and bioaugmentation but the TCE concentrations started rebounding between April and June 2009 due to limited electron donor availability. Based on the lack of complete conversion of TCE to ethene in the upper part of the active cell, combined with less favorable conditions observed at well AMW-1, the electron donor injection strategy was modified again by increasing the volume and concentration of weekly electron donor injections.

Complete reductive dechlorination of TCE to ethene was observed in the upper half of the active cell following the increase in electron donor volume and concentration that began in June 2009. As of October 2009, TCE degradation ranging from 85 percent to 99.7 percent was achieved in the upper portion of the active cell. In addition, large increases in VC concentrations ranging from 510 µg/L to 6,000 µg/L, and significant ethene production ranging from 47 µg/L to 1,500 µg/L at wells AMW-1 and AMW-2, and all three zones of the three CMT wells, indicated that complete dechlorination was achieved. Zone 2 of the CMT wells appeared to be the most impacted with much higher ethene production observed, followed by zone 1 and then zone 3.

At well AMW-6, TCE concentrations decreased by 79 percent, DCE concentrations increased by 642 percent, and dramatic increases in VC concentration from below detection limit to 4,900 µg/L were observed in October 2009. Because little change was observed in the COD and redox data at AMW-6, these VOC results suggest that the shift in VOC concentration is a result of biodegradation occurring upgradient and degradation products being transported to this well. Similarly, at well AEW, TCE concentrations increased by 50 percent, DCE concentrations increased by 15 percent, and a large increase in VC concentration from 48 µg/L to 510 µg/L was observed in October 2009.

Once complete reductive dechlorination of TCE to ethene was achieved, a loss of chloroethene mass balance was observed at all the wells located in the upper half of the active cell. This phenomenon has been observed at other sites with similar conditions, namely shallow, relatively "thin" contaminated aquifers (e.g., French et al, 2003). This result can at least partially be attributed to the volatilization of VC and ethene to the vadose zone.

In summary, complete reductive dechlorination of TCE to ethene was achieved only in the upper half of the active cell (greater than 36 feet downgradient and approximately 25 feet upgradient of the injection wells) as a function of electron donor distribution. An example of this is included in Figure 5-7 for AMW-1. Vertical distribution of electron donor appears effective with dechlorination of TCE to ethene being observed in all three zones of all the three CMT wells. However, Zone 2 of the CMT wells was impacted the most, followed by Zone 1 and Zone 3. It should also be noted that the considerable production of ethene occurred in the presence of high sulfate concentration and minimal methane production which confirmed that complete reductive dechlorination could be achieved in the presence of high sulfate concentrations.

CSIA data for the active cell generally were consistent with the CVOC data, in that they suggested degradation to VC and ethene was occurring. An example CSIA chart is included as Figure 5-8 for AMW-2. This chart shows a very "heavy" signature (less negative) for TCE, indicating that it has been substantially degraded. Also, c-DCE and VC also become heavier during the course of the demonstration, indicating degradation is occurring. Ethene was detected at this location, but not in high enough concentrations to be able to perform an isotope analysis. The rest of the active cell CSIA data are included in Appendix H.

5.8.1.4 Biological Indicators

Dechlorinating bacteria, pH, and alkalinity can serve as indirect lines of evidence for occurrence of biological activity within the aquifer. In particular, increase in numbers (i.e., growth) of dechlorinating bacteria suggests the occurrence of biodegradation of VOCs within the aquifer. These parameters are discussed below.

Dechlorinating Bacteria

DNA sampling was performed at the active cell wells to evaluate the presence of the dechlorinating bacteria *DHC* prior to bioaugmentation, and more importantly, the success of bioaugmentation following inoculation of bacteria. Complete results for the active cell are provided in Table H-1 and figures showing the key DNA trends are presented in Appendix H.

During the baseline sampling event, low numbers of *DHC* (16S rRNA and functional genes *tceA* and *bvcA*) on the order of 10^2 gene copies/L were observed only at well AEW within the active cell. The functional gene *vcrA* was not observed at any well within the active cell.

During the pre-conditioning phase low numbers of *DHC* bacteria (16S rRNA and/or functional genes *tceA* and *bvcA*) on the order of 10^2 gene copies/L to 10^4 gene copies/L were observed at wells AMW-2 (November 2008), AMW-4 (Z1) (November 2008), AMW-5 (Z1) (May 2008 and September 2008), AMW-6 (September 2008), and continued to be observed at well AEW (May through November 2008). However, the functional gene *vcrA* was not observed at any well within the active cell. The DNA results suggested the need for bioaugmentation within the active cell, and also confirmed that the *vcrA* gene could be used as a biomarker for the introduced culture (refer to Section 6.3.1).

Following bioaugmentation and during injection of one percent sodium lactate, considerable increases in numbers of *DHC* bacteria (ranging from $> 10^6$ gene copies/mL to $> 10^9$ gene copies/mL) and all three functional genes (*tceA*, *bvcA*, and *vcrA*) were observed in all wells in the upper portion of the active cell: AMW-1, AMW-2, and all zones of CMT wells (AMW-3, -4,

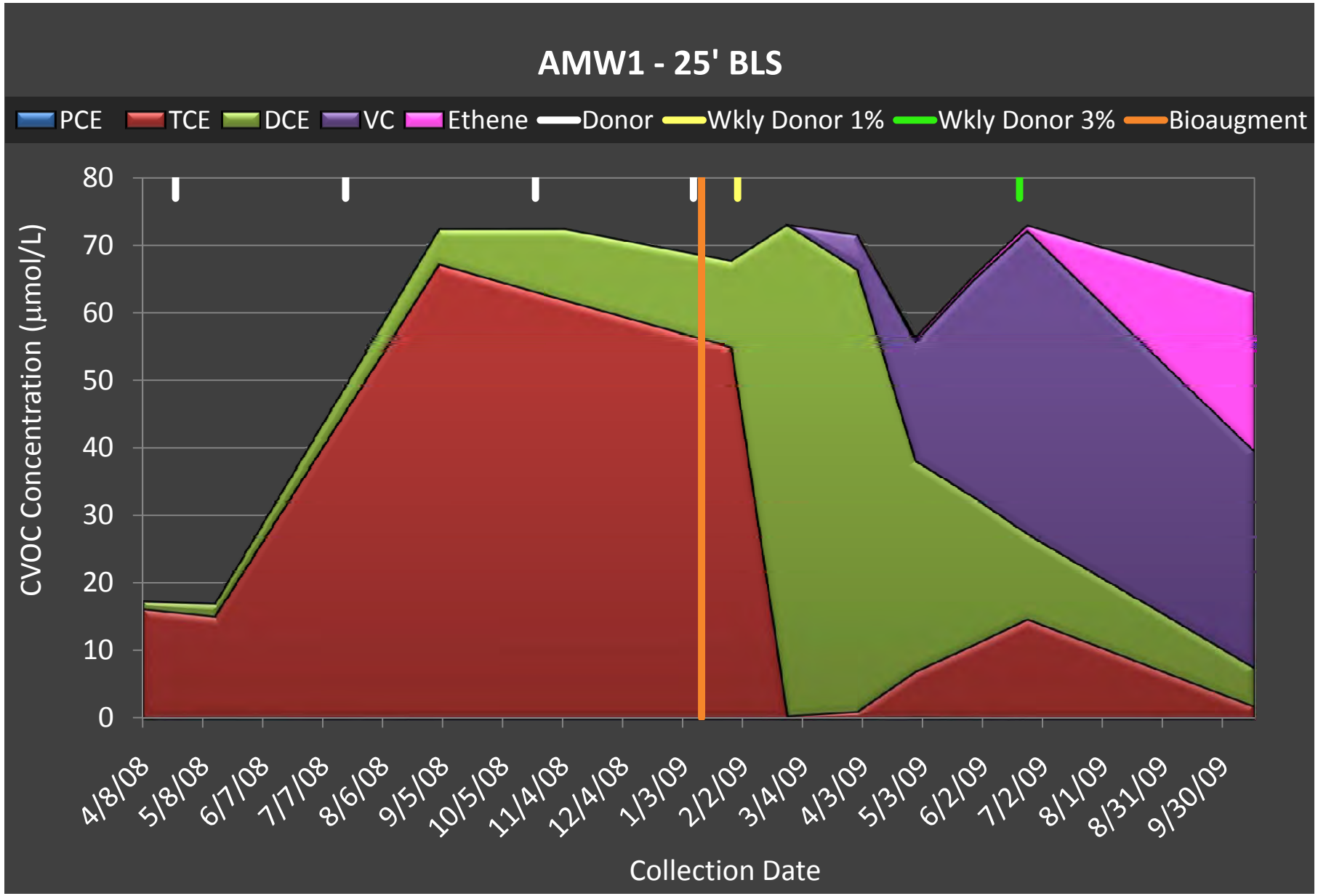
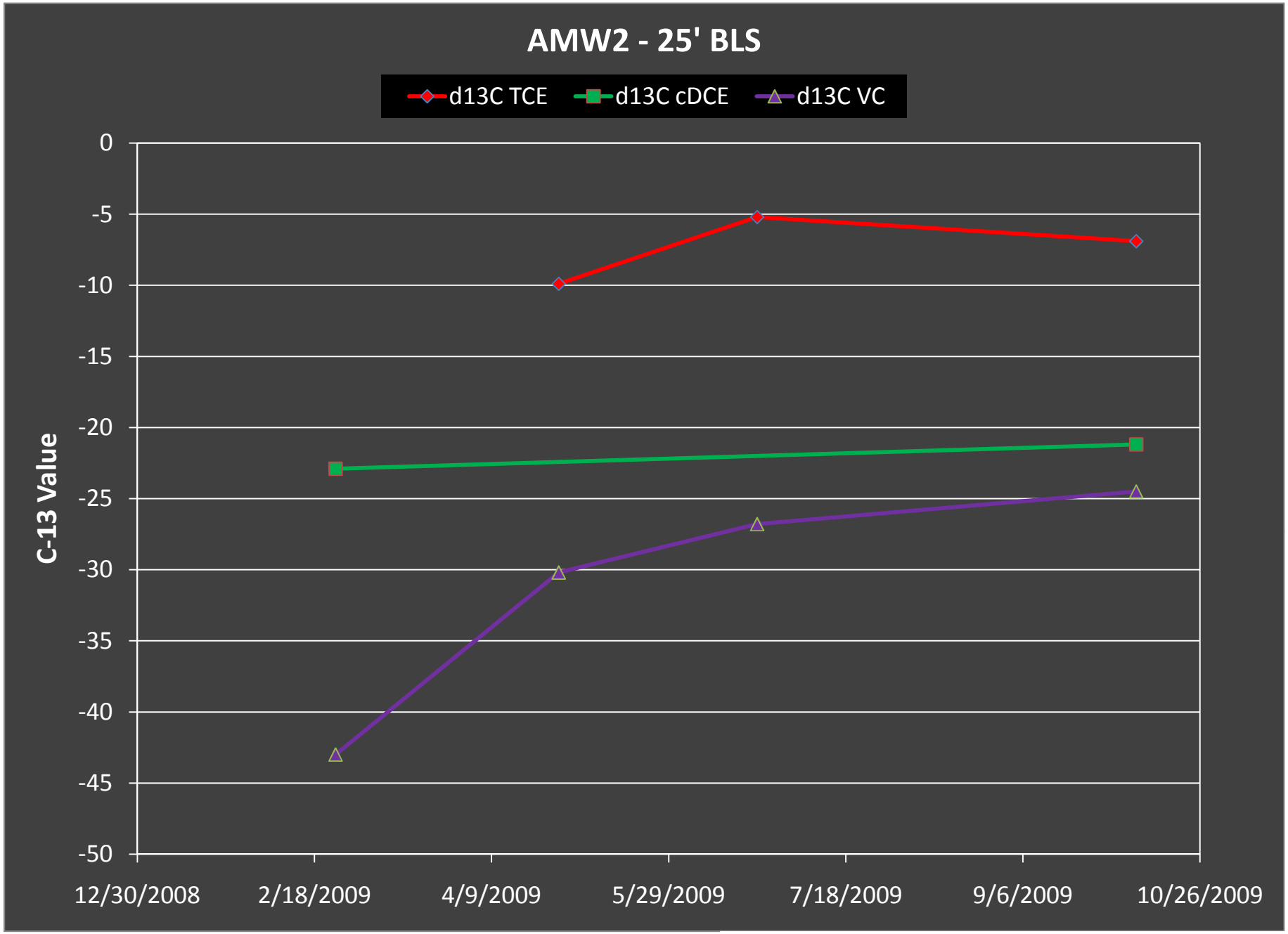


Figure 5-7
CHLORINATED VOC MOLAR CONCENTRATION TREND, AMW-1
NAVWPNSTA SEAL BEACH SITE 70
SEAL BEACH, CALIFORNIA

Recirculation system was shut off between 9/2/2008 and 1/6/2009.



Recirculation system was shut off between 9/2/2008 and 1/6/2009.

Figure 5-8
CSIA RESULTS FOR AMW-2
NAVWPNSTA SEAL BEACH SITE 70
SEAL BEACH, CALIFORNIA

and -5). However, a decline in *DHC* populations (for example, 2 order of magnitude decrease at well AMW-4 (Z1) in June 2009) was soon observed within the upper half of the active cell. Low numbers of *DHC* bacteria were observed at well AMW-6 and AEW indicating that these wells were not being impacted. The decline in numbers of *DHC* bacteria combined with the COD and VOC data indicated that donor injection strategy needed to be optimized further in order sustain and advance reductive dechlorination within the active cell.

The increase in weekly electron donor injection concentration from 1 percent to 3 percent sodium lactate solution resulted in increases or sustenance of the numbers of *DHC* bacteria and/or the functional genes in the upper portion of the active cell: AMW-1, AMW-2, and all zones of CMT wells (AMW-3, -4 and -5 except well AMW-3 (Z3) and AMW-5 (Z1)). Low numbers of *DHC* bacteria observed at well AMW-6 and AEW indicated that these wells were still not being impacted by the remedy. An example of the *DHC* population trends is presented in Figure 5-9 for AMW-1.

Overall, the dechlorination trends throughout the demonstration, the complete conversion of TCE to ethene only after bioaugmentation, and the DNA results indicate that bioaugmentation was successful for the upper half of the active cell. Because low levels of *DHC* were detected prior to bioaugmentation (specifically the bvcA and tceA genes), it is possible that some of the *DHC* present in the active cell was from growth of indigenous bacteria. However, the bioaugmentation culture also contained these functional genes, so it is also possible that majority of DHC was from the added culture. While it is not clear exactly whether all of the *DHC* present in the active cell were from the added culture, the most important point is that the vcrA results indicate that *DHC* bacteria that were added during bioaugmentation were transported to monitoring wells throughout the upper half of the active treatment cell. In addition, vertical distribution of *DHC* appeared to be effective, with complete dechlorination to ethene and *DHC* bacteria observed in all 3 zones of all CMT wells.

pH

While pH is not an indicator of reducing conditions or dechlorination, it can indicate whether aquifer geochemistry is favorable for biological activity. pH levels in the appropriate range (5.0< pH <9.0) provide verification that the progress of dechlorination (i.e., survival and performance of the *DHC* bacteria) within the pilot test area is not being hindered (EPA 1998). Complete results of pH measurements are included in Table H-1.

pH levels were observed to decrease slightly following electron donor injection, particularly following weekly electron injections of 1,000 gallons of 3 percent sodium lactate solution. But as of October 2009, pH levels were greater than 5.2 within the active cell. This indicates that appropriate pH levels have been maintained within the active cell area, and that the aquifer has sufficient buffering capacity.

Alkalinity

Alkalinity is an indicator of microbial respiration because carbon dioxide production increases bicarbonate at typical groundwater pH levels. Alkalinity is also increased by the fermentation of injected electron donor, providing an indication of whether electron donor utilization is occurring in the treatment area. Complete results for alkalinity are presented in Table H-1.

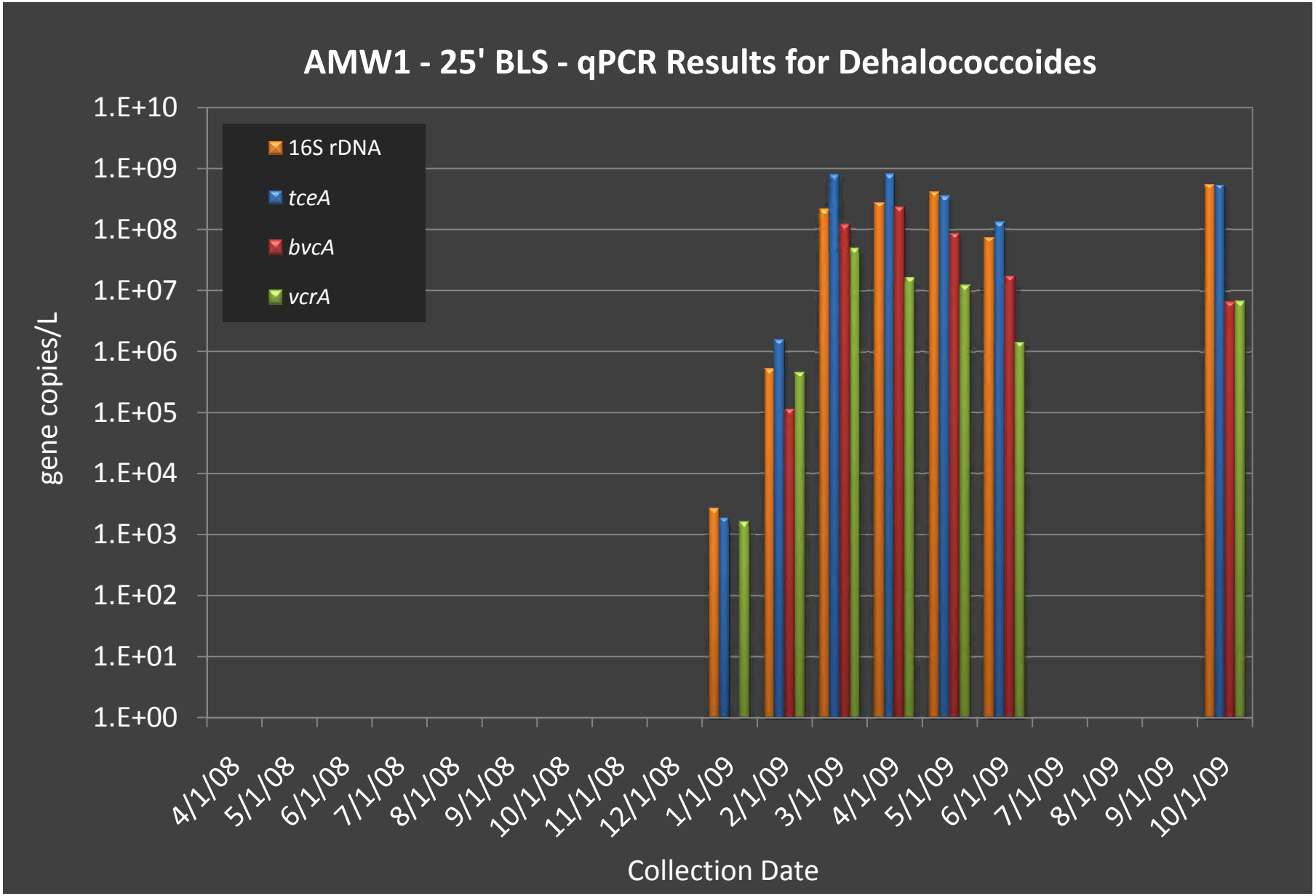


Figure 5-9
DEHALOCOCCOIDES SPP. CONCENTRATION TREND, AMW-1
NAVWPNSTA SEAL BEACH SITE 70
SEAL BEACH, CALIFORNIA

Recirculation system was shut off between 9/2/2008 and 1/6/2009.

During the baseline sampling event, alkalinity values ranging between 450 mg/L and 860 mg/L were observed. Alkalinity values were observed to increase at all the wells in the upper portion of the active cell. As of October 2009, alkalinity values ranging between 870 and 1,900 mg/L were observed. Alkalinity values mostly remained near background at wells AMW-6 and AEW. The elevated alkalinity values observed at the wells in the upper portion of the active cell indicate the presence of biological activity (specifically electron donor utilization) within the active cell.

5.8.2 Passive Cell

5.8.2.1 Electron Donor Distribution

Complete COD results for the passive cell are included in Table I-1, and figures showing the key COD concentration trends are presented in Appendix I. The baseline sampling event (April 2008) showed COD concentrations ranging between 16 and 100 mg/L in the passive cell wells. During the pre-conditioning phase, the COD concentrations were observed to increase significantly only in the central and lower portion of the passive cell with concentrations above 1,000 mg/L observed at injection wells PIW-2 and PIW-3 and monitoring wells PMW-7 and PMW-8. Much lower COD values were observed in the upper portion of the passive cell with concentrations near or above 100 mg/L observed at injection well PIW-1 (September and November 2008) and wells PMW-2 and PMW-3 (Z1) (November 2008). COD concentrations at the upgradient well PMW-1 and all other monitoring wells and zones remained near background during the pre-conditioning phase.

At injection wells PIW-2 and PIW-3 and monitoring wells PMW-7 and PMW-8, COD concentrations continued to remain above 1,000 mg/L during the post-bioaugmentation phase, with the exception of well PIW-2 where concentrations decreased in October 2009 to 920 mg/L. At well PMW-6 COD concentrations increased above 1,000 mg/L but were observed to decrease in October 2009 (400 mg/L) whereas COD concentrations at well PMW-9 showed an increase in COD concentrations in the range of a few hundred mg/L. Thus, in the central and lower portion of the passive cell, the extent of electron donor distribution was expanded to include wells PMW-6 and PMW-9 during the post-bioaugmentation phase.

During the post-bioaugmentation phase, COD concentrations at upgradient well PMW-1 and injection well PIW-1 remained near baseline except in June and October 2009 when small increases in concentration to about 60 mg/L and 45 mg/L (near 2X baseline), respectively, were observed. Samples were collected from two different depth intervals (25 feet and 35 feet bgs) at injection well PIW-1 in March 2009 to better understand the distribution of electron donor at this well. But very similar concentrations (28 mg/L at 25 feet bgs and 30 mg/L at 35 feet bgs) were observed, leaving the reason for the significant difference in COD concentrations between injection wells PIW-2 and PIW-3 and injection well PIW-1 unknown. At well PMW-2 the COD concentration remained near baseline, except in October 2009 (410 mg/L). COD concentrations at the CMT wells were observed to increase above 1,000 mg/L at wells PMW-3 (Z2 and Z3), PMW-4 (Z3), and PMW-5 (Z2) and in the range of a few hundred mg/L in all other zones. Zone 2 of the CMT wells appeared to be the most impacted with higher COD values followed by zone 3 and then zone 1. Thus in the upper portion of the passive cell, the extent of electron donor distribution was expanded to include all three CMT wells during the post-bioaugmentation phase.

In general, COD concentrations increased and resulted in good donor distribution within the treatment zone of the passive cell extending approximately 22 feet downgradient and 15 feet cross-gradient of the injection wells. Effects of donor injections were observed a few months earlier in the central and lower portion of the compared to the upper portion of the passive cell. Vertical distribution appeared effective, with the impact of donor observed more in zones 2 and 3 compared to zone 1 of CMT wells. Overall, the results suggest that electron donor can be easily injected using slug injections and effectively distributed to at least 22 feet downgradient using the passive injection approach at the Site. Figure 5-10 shows an example COD concentration trend for PMW-7.

5.8.2.2 Redox conditions

ORP measurements and concentrations of inorganic electron acceptors (DO, nitrate, ferrous iron, sulfate and methane) for the passive cell are included in Table I-1 and figures showing the key redox conditions trends are presented in Appendix I.

ORP

ORP values at all the passive cell wells were mostly high and ranged from -60 mV to 484 mV during the baseline sampling event. Following electron donor injections, ORP values were observed to decrease as a function of electron donor distribution and reached the appropriate range at all the passive cell wells. As of October 2009 the ORP values were observed below 50 mV at all the passive cell wells, and were observed near or below -100 mV at all three injection wells and monitoring wells PMW-2, PMW-3 (Z3), PMW-6, PMW-7, PMW-8, and PMW-9. Overall, the ORP values at injection and monitoring wells were in the appropriate range for dechlorination and suggest establishment and sustenance of moderate to strongly reducing conditions within the passive cell.

Electron Acceptors and Reduced Products

The changes in the concentrations of various electron acceptors and their reduced products throughout the pilot test within the passive cell are discussed below.

Dissolved Oxygen

DO was not a reliable redox indicator during this demonstration, likely because of equipment problems, and is not discussed here.

Nitrate Reduction

The baseline sampling event showed nitrate concentrations less than 1 mg/L at all the passive cell wells. The already low nitrate concentrations were reduced and observed mostly near or below detection limit at all the passive cell wells during the pilot test with the exception of the upgradient well PMW-1 which showed nitrate concentrations near baseline. Overall, the results indicate that nitrate reduction was not an important process within the passive cell due to the low initial nitrate concentrations.

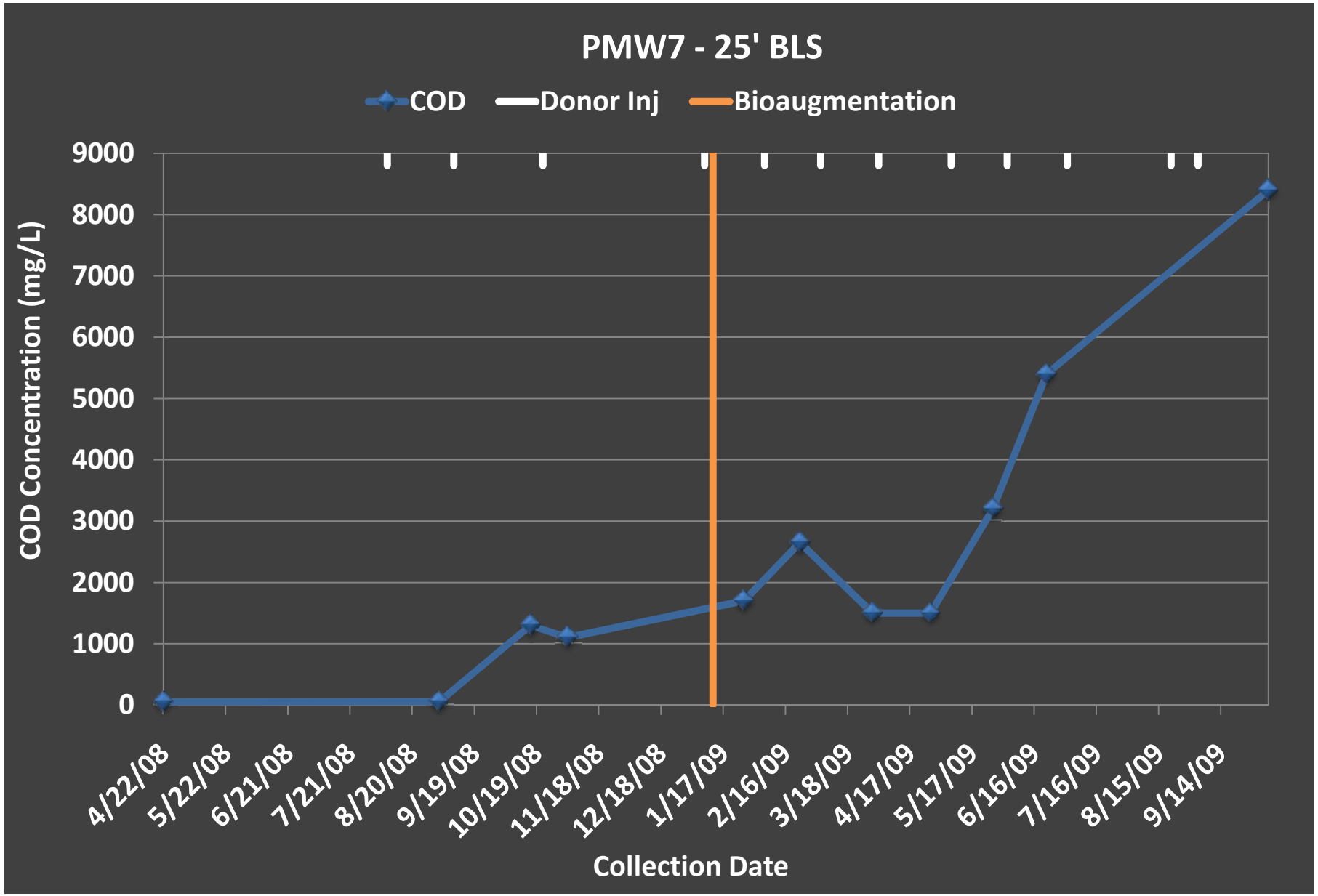


Figure 5-10
COD CONCENTRATION TREND, PMW-7
NAVWPNSTA SEAL BEACH SITE 70
SEAL BEACH, CALIFORNIA

Iron Reduction

The baseline sampling event showed ferrous iron concentrations below the detection limit at all the passive cell wells except wells PMW-4 (Z5) (0.53 mg/L), PMW-5 (Z3) (0.015 mg/L), and PMW-5 (Z4) (0.76 mg/L). Elevated ferrous iron concentrations were observed at all the passive cell wells except the upgradient well PMW-1 and injection well PIW-1 following electron donor injection. Elevated ferrous iron concentrations were observed at zones 1 to 3 of the three CMT wells. Following the initial increase, ferrous iron concentrations were found to decrease at some of the wells over time (PIW-2, PMW-2, and PMW-6 through PMW-9). The blackish water observed during sampling event at these wells suggests the production of reduced iron sulfide minerals that explains the decrease in aqueous ferrous iron. Overall, the results indicate that iron reducing conditions were established at most of the wells within the passive cell.

Sulfate Reduction

Baseline sulfate concentrations were above 1,000 mg/L in all the passive cell wells and ranged from 1,100 mg/L to 5,800 mg/L. Baseline sulfate concentrations were generally higher in zones 2 and 3 of CMT wells (3,900 mg/L to 5,800 mg/L) compared to zone 1 (2,000 mg/L). Following electron donor injections, sulfate concentrations decreased significantly at injection wells PIW-2 and PIW-3 and monitoring wells PMW-2, PMW-7, and PMW-8 with removal ranging between 76 percent and 100 percent in October 2009. Significant decreases in sulfate concentrations were also observed at wells PMW-3 (Z2) and PMW-6 with removal of greater than 75 percent in June 2009, however; rebound in sulfate concentrations were observed at these wells in October 2009. Little sulfate reduction was observed at wells PMW-4 (Z3) (30 percent removal) and PMW-5 (Z2) (19 percent removal) in October 2009. At well PMW-9 sulfate reduction was observed, but the sulfate concentrations varied. At upgradient well PMW-1 and other zones of the CMT wells, sulfate concentrations were observed near baseline. Overall, sulfate reduction was observed at most of the wells in the central and lower portion of the cell, and at wells PMW-2 and PMW-3 (Z2) in the upper portion of the passive cell.

Methanogenesis

During the baseline sampling event, low methane concentrations (less than 0.5 mg/L) were observed at all the passive cell wells with the exception of wells PIW-1 (2.3 mg/L) and PMW-9 (2.8 mg/L). A significant increase in methane concentration (greater than 0.5 mg/L) was observed as a result of lactate injections in all three injection wells and monitoring wells PMW-2, PMW-3 (Z2), PMW-4 (Z1), PMW-5 (Z1), and PMW-6 through PMW-9. However, with the lack of sulfate reduction observed at wells PMW-4 (Z1) and PMW-5 (Z1), methane might not have been generated locally at these wells but transported from upgradient. At all other wells and zones methane concentrations were observed near baseline.

At the injection wells, methane production was observed almost 9 months (January 2009) after beginning monthly donor injections, and at most of the monitoring wells, increases in methane concentration were observed about 13 months (May 2009) to 17 months (October 2009) after beginning monthly donor injections. At all the above mentioned wells except injection well PIW-3, methane production was observed in the presence of high sulfate concentrations indicating that all sulfate present does not need to be reduced

before methanogenic conditions are established. Overall, methanogenic conditions were observed at most of the wells in the central and lower portion of the passive treatment cell and at wells PIW-1 and PMW-2 in the upper portion of the passive cell.

Redox Summary

Based on the results discussed in this section, it can be concluded that redox conditions shifted in accordance with the electron donor distribution, and as of October 2009, moderate to strongly reducing conditions had been established within the passive cell. Methanogenic conditions appeared to be established in the upper portion (wells PIW-1 and PMW-2) and in the central and lower portions (wells PIW-2, PIW-3, PMW-6 through PMW-9) of the passive cell. Iron reducing conditions with little to no sulfate reduction appeared to be established within zones 1 to 3 of all three CMT wells except at well PMW-3 (Z2) where sulfate reducing conditions were achieved. It should be noted that unlike the active cell, no effects of donor injections were observed at the upgradient well, PMW-1, of the passive cell. Typical electron acceptor concentrations are presented in Figure 5-11 for PMW-8.

5.8.2.3 VOC Concentrations

VOC results for the passive cell are presented in Table I-1 and figures showing the key VOC concentration trends are presented in Appendix I. Baseline groundwater contamination (April 2008) was characterized by high chloroethene concentrations primarily consisting of TCE at the passive cell wells. In the upper portion of the passive cell, TCE concentrations on the order of 1,100 µg/L to 2,600 µg/L were observed at wells PMW-1 and PMW-2, whereas injection well PIW-1 showed very low total CVOC concentration of 64 µg/L. Zone 1 of all three CMT wells (PMW-3 to PMW-5) was characterized by very high chloroethene concentrations on the order of 50,000 to 60,000 µg/L. Zones 2 and 3 of the three CMT wells consisted of concentrations of nearly 5,000 to 17,000 µg/L. In the central and lower portion of the passive cell, TCE concentrations were approximately 10,000 to 20,000 µg/L (wells PIW-2, PIW-3, PMW-6, PMW-7, and PMW-8), with the exception of well PMW-9 where a TCE concentration of 840 µg/L was observed. DCE concentrations were very low (below detection limit to 120 µg/L) and VC and ethene were not detected in any passive cell well.

During the pre-conditioning phase (April to November 2008), TCE concentrations decreased by >97 percent at the injection wells PIW-2 and PIW-3 without a corresponding increase in the degradation products. At injection well PIW-1, chloroethene concentrations continued to remain low. During the first sampling event following electron donor injections (September 2008) a slight increase in TCE and total chloroethene concentrations was noted at a few of the monitoring wells (PMW-2, PMW-3 (Z1), PMW-6, and PMW-9), including the upgradient well PMW-1, with the increase in total CVOCs ranging from 1.1X to 2.4X baseline. Following the initial increase, TCE concentrations decreased at all the wells within the passive cell except at well PMW-3 (Z1), and by November 2008 TCE decreases ranging between 11 percent and 53 percent were observed. However, no notable increase in any of the degradation products (DCE, VC, or ethene) was observed at these wells.

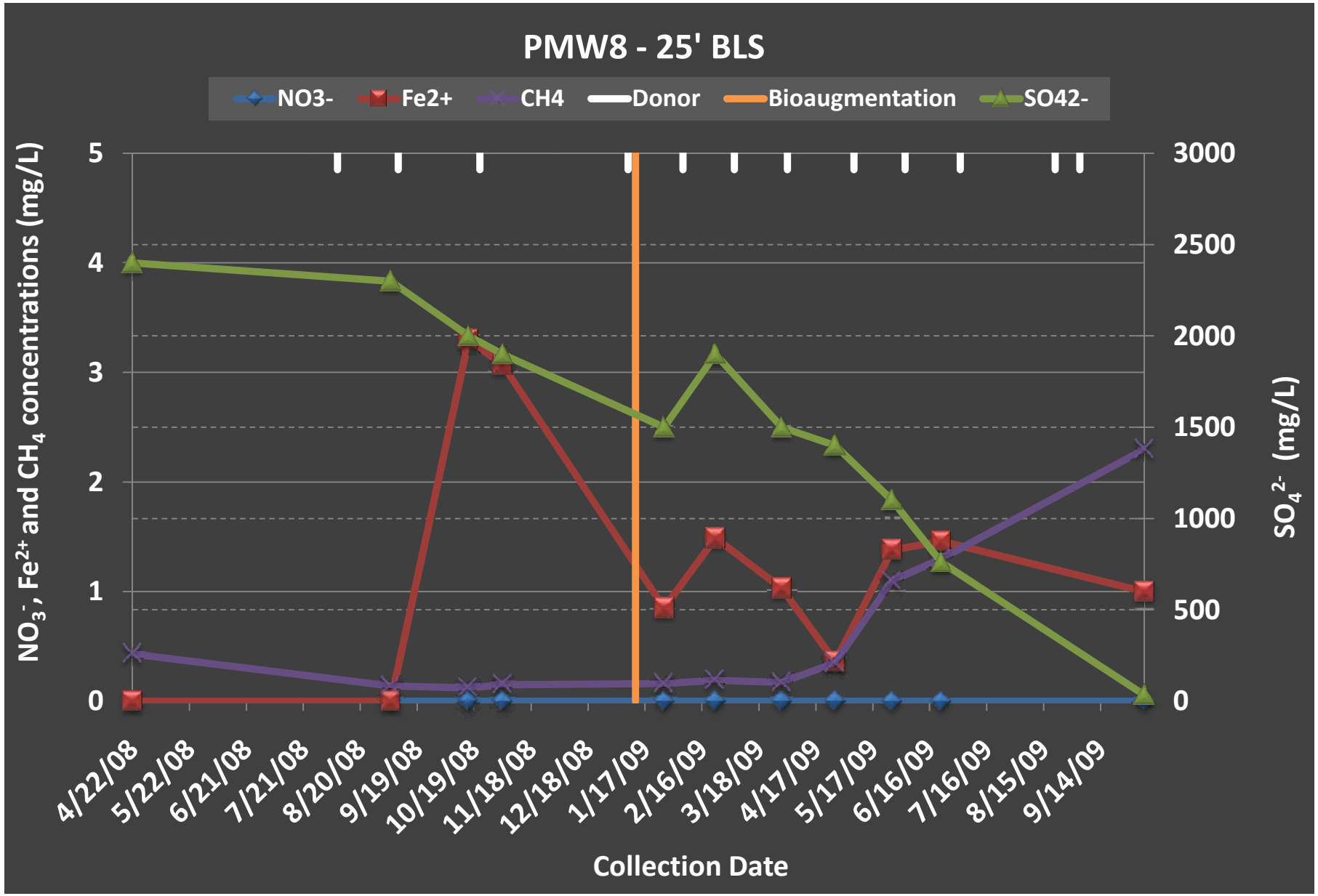


Figure 5-11
ELECTRON ACCEPTOR CONCENTRATION TREND, PMW-8
NAVWPNSTA SEAL BEACH SITE 70
SEAL BEACH, CALIFORNIA

During the post-bioaugmentation phase, TCE and DCE were mostly removed, with VC and ethene observed for the first time at injection wells PIW-2 and -3 within two weeks after inoculation, in January 2009. Complete conversion of TCE to ethene was also observed at injection well PIW-1. As of October 2009, total CVOCS continue to remain low at all three injection wells. The concentrations at the upgradient well PMW-1 remained unchanged during the post-bioaugmentation phase.

Little to no dechlorination was observed in the upper portion of the passive cell during the post-bioaugmentation phase. At well PMW-2 the TCE concentration decreased through March 2009 followed by rebound in TCE concentration observed between April and June 2009, but the concentration decreased again in October 2009. The decrease in TCE concentration at well PMW-2 was not accompanied by a corresponding increase in the degradation products. As of October 2009, CVOC concentrations remain unchanged at CMT well PMW-3 (Z1) and a decrease in TCE and increase in DCE with little VC production was observed at wells PMW-4 (Z1) and PMW-5 (Z1). As of October 2009, TCE removal greater than 44 percent and DCE concentrations greater than 10,000 µg/L were observed at wells PMW-4 (Z1) and PMW-5 (Z1), and a VC concentration of 490 µg/L was observed at well PMW-5 (Z1). At well PMW-5 (Z2) some DCE production was observed in October 2009 (220 µg/L). At all other zones of the CMT wells the total CVOC concentrations varied but primarily consisted of TCE and no biodegradation was observed.

Complete reductive dechlorination of TCE to ethene was observed in the central and lower portion of the passive cell as shown by the VOC results at wells PMW-6 through PMW-9. In October 2009 biodegradation accounted for reduction of total CVOC concentrations by greater than 92 percent at wells PMW-7 through PMW-9 and nearly 72 percent at well PMW-6 compared to CVOC concentrations observed in November 2008, immediately before bioaugmentation. Ethene production was observed as high as 410 µg/L at wells PMW-6 through PMW-9.

In summary, the VOC data indicate that complete reductive dechlorination was achieved in the central and lower portions (around injection wells PIW-2 and PIW-3) of the passive cell. However, complete reductive dechlorination was not observed in the upper portion of the passive cell (around injection well PIW-1) although effective electron donor distribution and redox conditions appropriate for dechlorination were achieved. CVOC molar concentrations are presented in Figure 5-12 for PMW-9.

CSIA data for the passive cell generally were consistent with the CVOC data, in that they suggested degradation to VC and ethene was occurring near PIW-2 and PIW-3, but not in the vicinity of PIW-1. An example CSIA chart is included as Figure 5-13 for PMW-6. This chart shows that TCE, c-DCE, and VC became heavier during the course of the demonstration, indicating degradation is occurring. Ethene was much "lighter" during the last sampling event compared to the previous two. The rest of the active cell CSIA data are included in Appendix H.

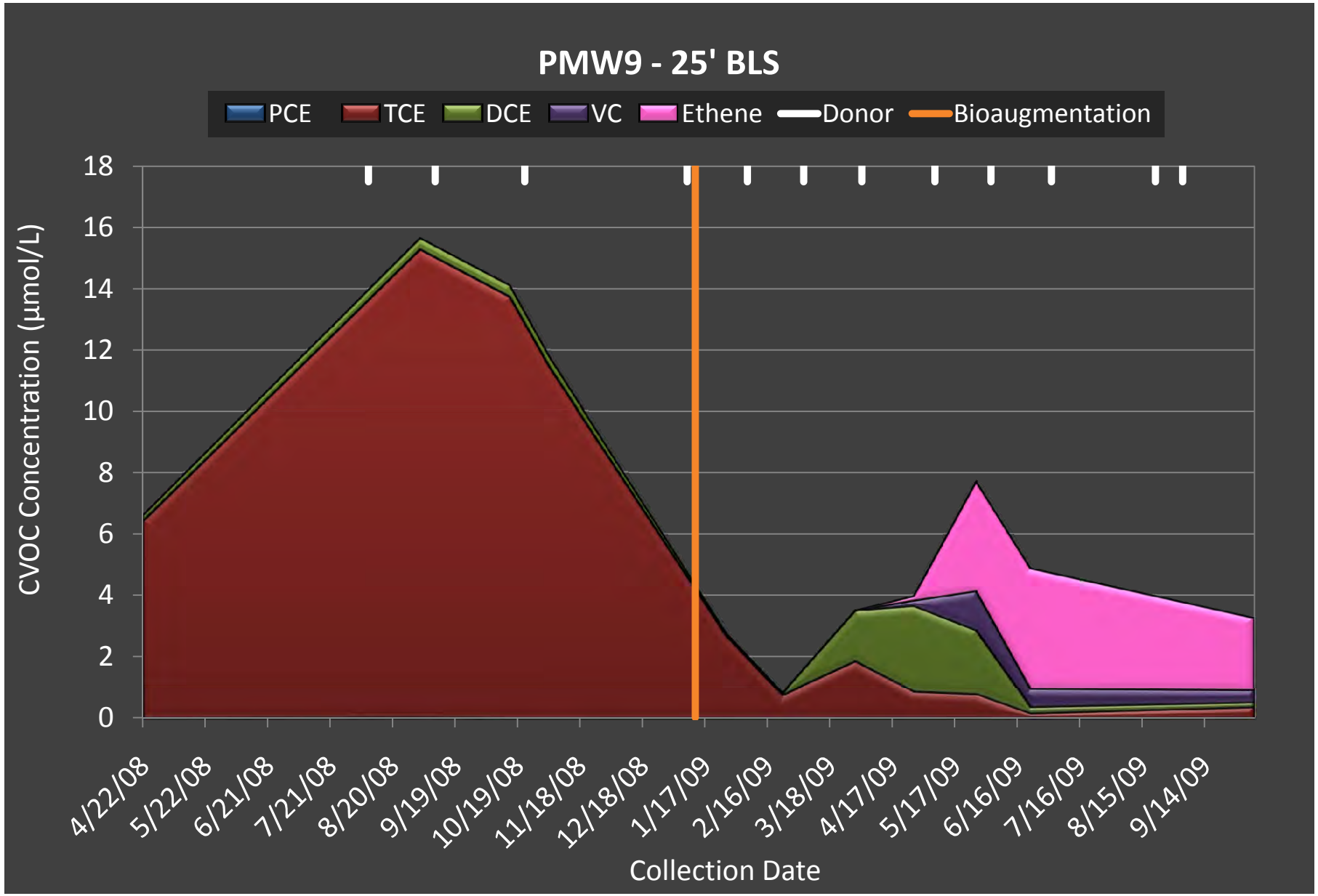


Figure 5-12
CHLORINATED VOC MOLAR CONCENTRATION TREND, PMW-9
NAVWPNSTA SEAL BEACH SITE 70
SEAL BEACH, CALIFORNIA

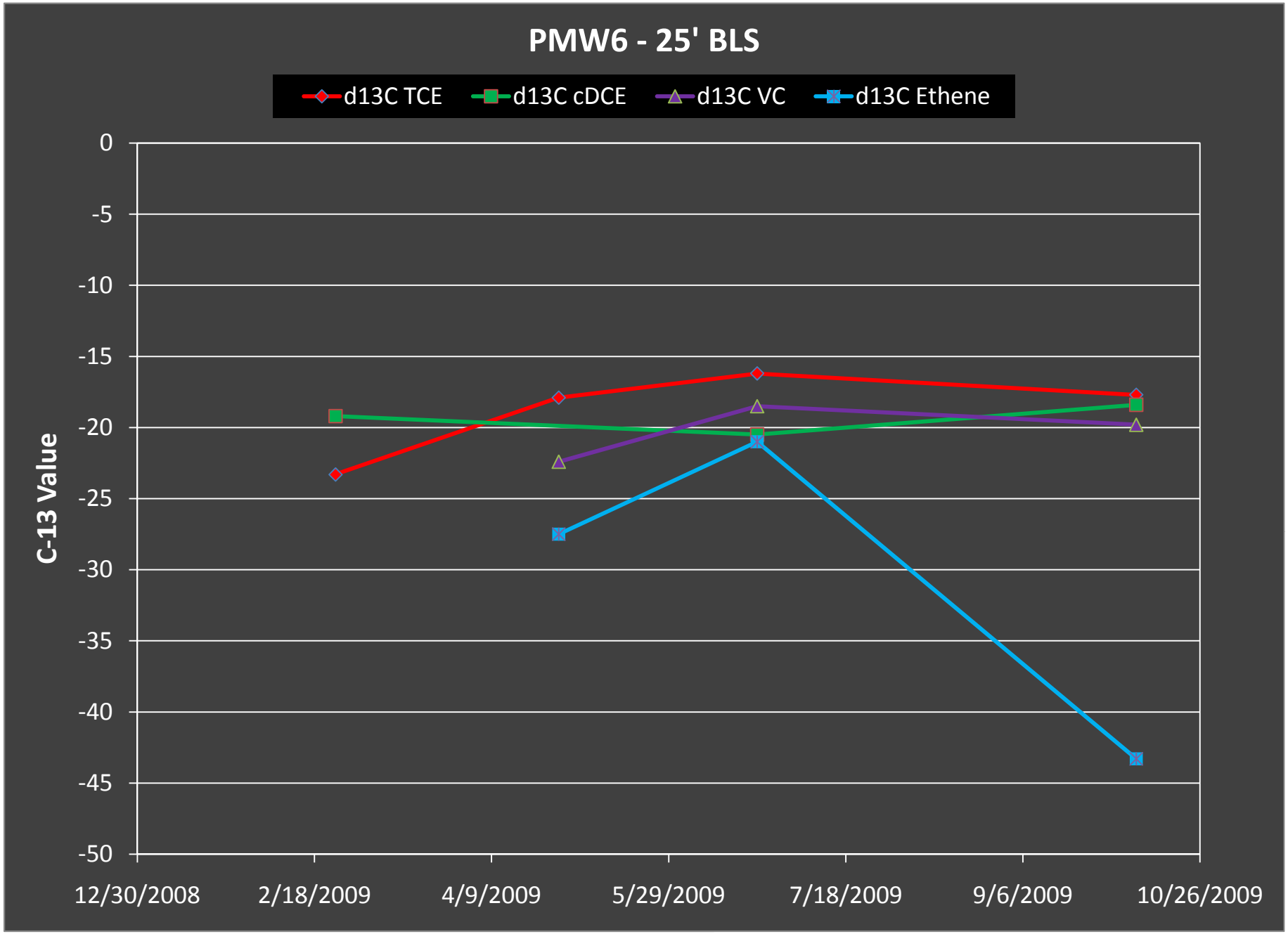


Figure 5-13
CSIA RESULTS FOR PMW-6
NAVWPNSTA SEAL BEACH SITE 70
SEAL BEACH, CALIFORNIA

5.8.2.3 Biological Indicators

Changes in numbers of dechlorinating bacteria and values of pH and alkalinity are discussed below.

Dechlorinating Bacteria

DNA results for the passive cell are provided in Table I-1 and figures showing the key DNA number trends are presented in Appendix I. During the baseline sampling event, *DHC* bacteria numbers were below detection limit at all the wells except well PMW-3 (Z1) which showed low numbers of *DHC* bacteria along with functional gene *tceA* ($>10^3$ gene copies/L).

During the pre-conditioning phase low numbers of *DHC* (16S rRNA and/or functional genes *tceA* and *bvcA*) were observed at a few wells (PMW-1, PMW-6, and PMW-7) ranging between $>10^1$ gene copies/L and $>10^3$ gene copies/L in September 2008. The functional gene *vcrA* was not detected in any well. The presence of dechlorinating bacteria in such low numbers at only a few wells, along with the absence of degradation products within the passive cell confirmed the need for bioaugmentation for reductive dechlorination to progress within the passive cell.

During the post-bioaugmentation phase, *DHC* bacteria and functional gene (*tceA* and *vcrA*) numbers increased immediately (within 2 weeks of inoculation) at all three injection wells on the order of $>10^6$ gene copies/L. As of October 2009, the numbers were observed to decrease by one to two orders of magnitude at the injection wells, suggesting that in the absence of high chloroethene concentrations, the *DHC* bacteria number might be decreasing. The functional gene *bvcA* was only detected in low numbers at well PIW-1 (May 2008).

In the upper portion of the passive cell, low detections of *DHC* bacteria and functional genes ranging between $>10^1$ gene copies/L and $>10^3$ gene copies/L were observed at the upgradient well PMW-1 and monitoring well PMW-2. In zone 1 of the CMT wells *DHC* bacteria and *tceA* gene numbers increased and were detected on the order of $>10^6$ gene copies/L and *vcrA* gene numbers were detected in the order of $>10^5$ gene copies/L and were sustained as of October 2009. Zones 2 and 3 of the CMT wells except well PMW-5 (Z3) also showed increases in numbers of *DHC* bacteria and functional genes *tceA* and *vcrA,* but the numbers were lower compared to Zone 1 of the CMT wells. In the central and lower portion of the passive cell (wells PMW-6 through PMW-9) *DHC* bacteria and functional gene (*tceA* and *vcrA*) numbers increased on the order of $>10^6$ gene copies/L and were sustained as of October 2009.

Overall, the DNA results combined with the VOC data suggest that bioaugmentation was successful; i.e., dechlorinating bacteria were successfully distributed and maintained, and complete reductive dechlorination was achieved in the central and lower portion of the passive cell. This is shown in Figure 5-14 for PMW-8. However, the DNA data combined with the COD data suggests that electron donor was distributed at higher concentrations in the upper zones (zones 2 and 3) of the CMT wells, whereas the bioaugmented culture was distributed (or at least survived) to a greater degree in zone 1 of the CMT wells. This discrepancy in distribution of electron donor and bioaugmented culture might be the reason that limited to no progress in reductive dechlorination was observed in the upper portion of the passive cell. The cause of this difference is unclear.

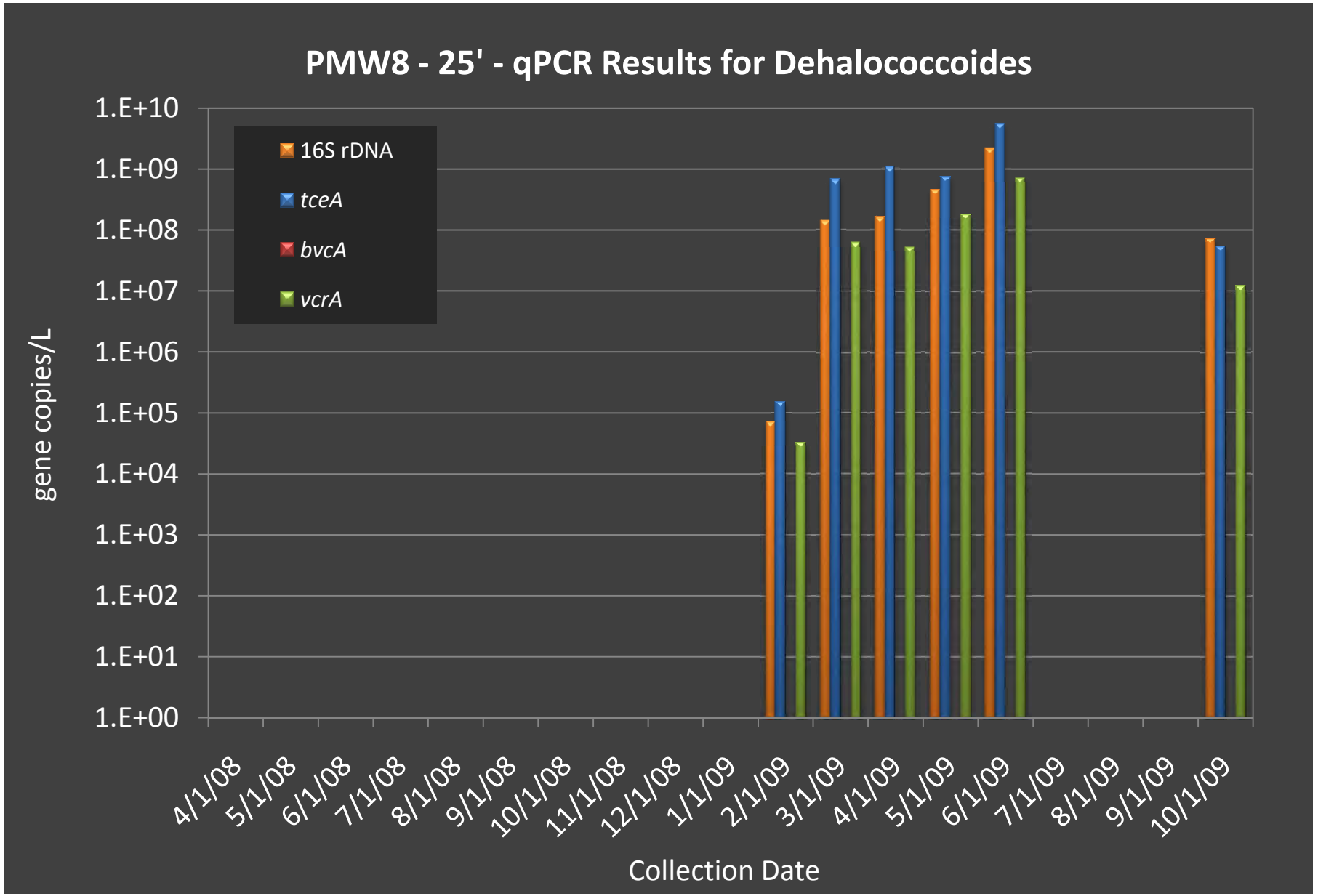


Figure 5-14
DEHALOCOCCOIDES SPP. CONCENTRATION TREND, PMW-8
NAVWPNSTA SEAL BEACH SITE 70
SEAL BEACH, CALIFORNIA

pH

Results of pH measurements are included in Table I-1. Significant pH impacts were not observed in any of the passive cell wells, and remained in the appropriate range (5.0<pH<9.0) during the pilot test, indicating that the aquifer has sufficient buffering capacity.

Alkalinity

Results for alkalinity are presented in Table I-1. During the baseline sampling event, alkalinity values ranging between 530 mg/L to 1,100 mg/L were observed at all the passive cell wells with the exception of well PMW-1 (1,400 mg/L), PIW-1 (1,900 mg/L), and zone 1 of the CMT wells (220 mg/L to 360 mg/L). Alkalinity values were observed to increase at all the wells within the passive cell except the upgradient well PMW-1 and injection well PIW-1. As of October 2009, the increased alkalinity values ranged from 1,400 to 5,200 mg/L at most of the wells with the exception of zone 1 of the CMT wells. In zone 1 of the CMT wells the increased alkalinity values ranged from 630 mg/L to 650 mg/L in October 2009 except well PMW-3 (Z1), where the alkalinity value peaked in February 2009 (680 mg/L), but was reduced to baseline by October 2009. The elevated alkalinity values observed at most of the wells within the passive cell compared to the near background values observed at the upgradient well PMW-1 and the injection well PIW-1indicate significant electron donor utilization within the passive cell.

6.0 PERFORMANCE ASSESSMENT

In the previous section, the test design and results were presented, including the data collected for bench scale testing, bioaugmentation culture selection, pre-conditioning, and bioaugmentation. In this section, the implications of those data are discussed in the context of the project performance objectives.

6.1 PHASE 1 PERFORMANCE OBJECTIVES – BENCH SCALE TESTING AND BIOAUGMENTATION CULTURE SELECTION

The purpose of the Phase 1 of the ER-0513 project was to conduct laboratory studies to confirm that dechlorination could be stimulated in the high sulfate environment present at NAVWPNSTA Site 70, and to select a bioaugmentation culture for the demonstration. These objectives were described in Section 3. The sections below assess performance of the demonstration activities in achieving these objectives.

6.1.1 Demonstration of Dechlorination using Site Groundwater

Section 5.4 and Appendix D present the results of the microcosm studies conducted as a part of Phase 1 demonstration activities. Two sets of microcosms were run, one with groundwater collected from existing well EW-70-01, and one with groundwater collected from MW-70-27. The success criterion for this performance objective was production of ethene at concentrations at least 2X detection, and reduction of TCE by at least 95% in the microcosms.

The results of the lab study showed that TCE was completely removed under all conditions investigated, which exceeded the goal of achieving at least 95% reduction of TCE. Microcosms from EW-70-01 showed that all CVOCs were converted to ethene with complete reduction of 1,650 mg/L sulfate. Microcosms from MW-70-27 showed that dechlorination of TCE to VC and ethene was achieved in less than four months using one of the two cultures, while TCE was converted to cis-DCE and VC using the other culture tested. These results show that three of the four conditions tested met the criteria of production of ethene of at least twice the detection limit. Based on these results, this performance objective was met.

6.1.2 Select Bioaugmentation Culture with Reliable Biomarker

Section 5.4 and Appendix E present the results of the DNA studies that were conducted as a part of Phase 1 demonstration activities. During the DNA study, several methods were used to evaluate *DHC,* including quantitative PCR analysis and clone library analysis to evaluate various genes including the 16S rRNA gene, and functional reductase genes *vcrA*, *bvcA* and *tceA*. These analyses were performed for the 16S rRNA gene of NAVWPNSTA Site 70 indigenous *DHC* and three bioaugmentation cultures. The DNA study also included *vcrA* gene sequence analysis of the SDC-9™ and KB-1™ bioaugmentation cultures. The success criterion for this objective was identification of a biomarker that is present in bioaugmentation culture(s) but not in native strains of *DHC*.

The results from the DNA study showed that the functional gene *vcrA* was not present at the site, but was present in both the SDC-9™ and KB-1™ commercially available bioaugmentation culture. In addition, DNA sequence information was obtained for the *vcrA* gene in both cultures

for the purpose of designing a new biomarker in the event that *vcrA* was detected at the end of the pre-conditioning phase. Based on the fact that the SDC-9™ culture had been demonstrated to perform better in the presence of co-contaminants detected at Site 70 compared to KB-1™ (i.e. chloroform), the SDC-9™ culture was selected for the demonstration. Therefore, this performance objective was met.

6.2 PHASE 2 PERFORMANCE OBJECTIVES – BASELINE CONDITIONS AND PRE-CONDITIONING

The purpose of Phase 2 of the ER-0513 project was to determine groundwater hydraulic conditions and baseline contaminant distribution, *DHC* distribution, and geochemical concentrations prior to beginning the biostimulation and bioaugmentation in each treatment cell. Performance objectives were established related to demonstrating that the treatment cell layout was such that meaningful results could be obtained during the timeframe of the project, and related to establishing appropriate conditions prior to conducting bioaugmentation. These objectives are discussed further below.

6.2.1 Treatment Cell Construction and Residence Time

Due to the slow ambient groundwater velocity in the Site 70 source area, ESTCP was concerned that effects of electron donor injections and bioaugmentation would not be observed at monitoring wells within the timeframe of the demonstration, at least for the passive cell. In addition, historical data that were available for the site did not provide conclusive information regarding groundwater flow magnitude and direction in the Upper Fines unit on the scale of the source area. In order to verify that meaningful results could be obtained using the proposed treatment cell layout, a tracer test was conducted to verify the groundwater hydraulic conditions in the treatment cells. Data collected in support of this objective included multiple samples collected from active cell and passive cell monitoring wells and analyzed for iodide tracer.

The success criterion for this objective was to construct the treatment cells such that travel time from injection wells to monitoring wells was 6 months or less. In the active cell, arrival of tracer occurred within 6 weeks of injection for AMW-1 through AMW-5, including at the two deepest zones of all of the CMT wells. Tracer was not observed at well AMW-6 (75 ft from injection wells) during the time it was sampled (this well also turned out to be too far from the injection wells for any effects of bioaugmentation or electron donor injection to be observed).

For the passive cell, a tracer test was conducted in order to confirm the results of the active cell tracer test. Because this test was merely to confirm approximate travel times predicted from the active cell tracer test, the frequent sampling that would be required to quantify hydraulic parameters was not performed. Rather, samples for tracer were collected 3 weeks and 5 weeks following injection, and then during planned pre-conditioning sampling events, which were conducted monthly from September through November. 1,000 gallons of iodide tracer were injected into PIW-1 on 8/7/08 at a concentration of approximately 13,000 mg/L as iodide. Tracer arrival was observed within 4 weeks at the deepest interval in PMW-4 (center CMT well located 17 ft downgradient), at the deepest zones of PMW-3 and -5, and at cross-gradient well PMW-2 within 7 weeks. By the end of the passive cell tracer monitoring period of 3.5 months, tracer was measured at PMW-2 through PMW-5, including at the two deepest zones of all CMT wells.

Overall, the results of the tracer test showed arrival in some wells in less than one month in both treatment cells, and subsequent sampling for tracer indicated that travel times to all monitoring wells that were installed near the tracer injection wells were less than 4 months. These tracer results show that meaningful data would be obtained within the 12 month planned duration of the demonstration. The groundwater velocities that were predicted for the passive cell based on the active cell tracer test were achieved during the demonstration. Therefore, this performance objective was met. In fact, as discussed below in Section 6.3, results were obtained faster than originally planned, such that the demonstration objectives were all met within a 9 month period.

6.2.2 Pre-Conditioning Results

Sampling was conducted to assess baseline conditions including contaminant and degradation product concentrations, redox parameters, and biological activity indicators (refer to Section 5.2 for complete baseline sampling results). In summary, the baseline results confirmed the pre-demonstration conditions in the source area; namely, that conditions were anaerobic but mildly reducing, with very high sulfate concentrations and very limited dechlorination to cis-DCE in some areas. Because these conditions were not ideal for bioaugmentation, electron donor additions were performed to "pre-condition" the aquifer to reduce sulfate concentrations and to drive redox conditions more strongly reducing.

The success criterion for this objective was to create at least sulfate-reducing conditions at monitoring wells nearest to injection locations, such that the bioaugmentation culture would have a favorable environment following inoculation. Results were presented in Section 5.7 and in a memo to ESTCP dated 12-28-2008 (see Appendix B). After three lactate injections into the active cell, results indicated that appropriate conditions were achieved for successful bioaugmentation, particularly in wells near the reinjection locations. Ferrous iron increased to above 0.5 mg/L in all wells except AMW-6 and upgradient well AMW-1. Also, sulfate concentrations decreased more than 10% except in AMW-6 and the extraction wells. While COD concentrations did not increase above 60 mg/L in any active cell well, the significantly increased cis-DCE concentration at AMW-2 and other wells indicated that partial dechlorination was already occurring near the injection wells.

After three passive cell injections, results indicated that conditions were becoming more reducing, with the most positive results observed near the injection wells. At these wells, ferrous iron increased to above 0.5 mg/L and sulfate decreased more than 10% except in PMW-2 and PMW-6. COD increased significantly at wells near the injection points also, and significant COD still remained at two of the three injection wells.

Another key result from the post-preconditioning sampling event was that the *vcrA* functional gene was not detected at any location in either the active or passive cell, despite the fact that low concentrations of *DHC* did appear following the biostimulation phase. These results confirmed that the *vcrA* gene could be used to track the bioaugmentation culture.

Overall, the post-preconditioning results indicated that sufficient electron donor was being supplied for bioaugmentation, and that redox conditions nearest the injection locations were

sulfate reducing to methanogenic in both treatment cells following the pre-conditioning phase. Therefore, this performance objective was met.

6.3 PHASE 3 PERFORMANCE OBJECTIVES – BIOAUGMENTATION RESULTS

The purpose of Phase 3 of the ER-0513 project was to demonstrate full-scale bioaugmentation and dechlorination using both the active and passive approaches. Phase 3 of the ER-0513 project began with inoculation of both treatment cells. Performance objectives were established related to collection of data that would allow for quantification of bacterial distribution and growth, and assessment of the extent of dechlorination. These objectives are discussed further below.

6.3.1 Bacterial Growth and Distribution

The first Phase 3 objective was to assess and quantify bacterial growth and distribution in both treatment cells. Bacterial distribution was assessed by analyzing the first arrival of *DHC* bacteria (as measured by qPCR analysis) at a giving monitoring location following inoculation. This travel time was then compared to the travel time for ambient groundwater, as determined from the tracer test. Bacterial growth was then assessed by analyzing the increase of *DHC* and functional gene counts at a given location once first arrival had been established. The success criterion for this objective was to collect data that allow for quantitative assessment of tracer and bacterial transport time, and growth of bacteria over time. No specific criteria were set in terms of bacterial transport times or cell counts. Therefore, this performance objective was met. The subsections below quantify the arrival of tracer and bioaugmentation culture based on *vcrA* analysis.

In general, the distribution of *DHC* bacteria was effective in both the active and passive cells. As shown in Figure 6-1, *DHC* concentrations exceeded 10^8 cells/L in both cells based on analysis of the 16S rRNA gene. In the active cell, the high *DHC* concentrations extended greater than about 30 ft downgradient from the injections wells. In the passive cell, the high concentrations were distributed throughout the downgradient two-thirds of the cell. Perhaps more importantly, concentrations of the *vcrA* gene, while somewhat lower than 16S rRNA gene measurements, indicated that the high *DHC* concentrations were representative of the bioaugmentation culture (Figure 6-2). The next two subsections discuss the speed at which the bacteria were distributed relative to groundwater velocity in the two cells.

6.3.1.1 Active Cell Distribution

Table 6-1 shows details for tracer arrival and first detection of *DHC* for the active treatment cell. Data are presented only for wells that were sampled monthly for *DHC* bacteria. While tracer samples were collected more frequently for the active cell CMT wells, *DHC* data were collected monthly from the deepest CMT port (Zone 1), and approximately quarterly from all other CMT ports. Because of this, the analysis of tracer and *DHC* arrival was only performed for Zone 1 of the CMT wells. Also, tracer data were not collected frequently enough at upgradient well AMW-1 to perform the analysis. For the active cell, tracer injection was performed on 4/10/08, and bioaugmentation was performed on 1/12/09.

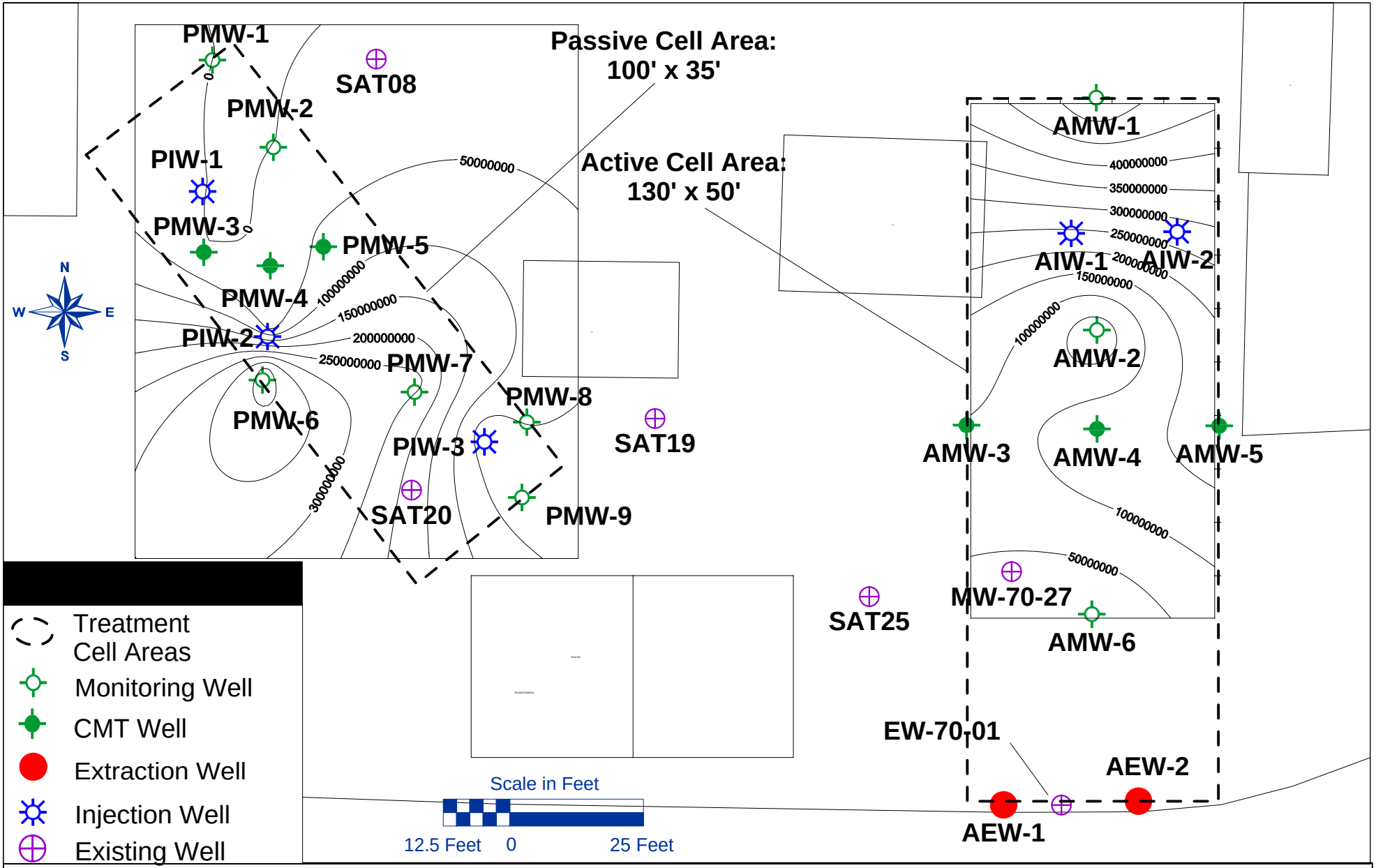


FIGURE 6-1
16S rDNA RESULTS, OCTOBER 2009
ER-0513 FINAL REPORT
SEAL BEACH NAVAL WEAPONS STATION, SEAL BEACH, CA

CDM

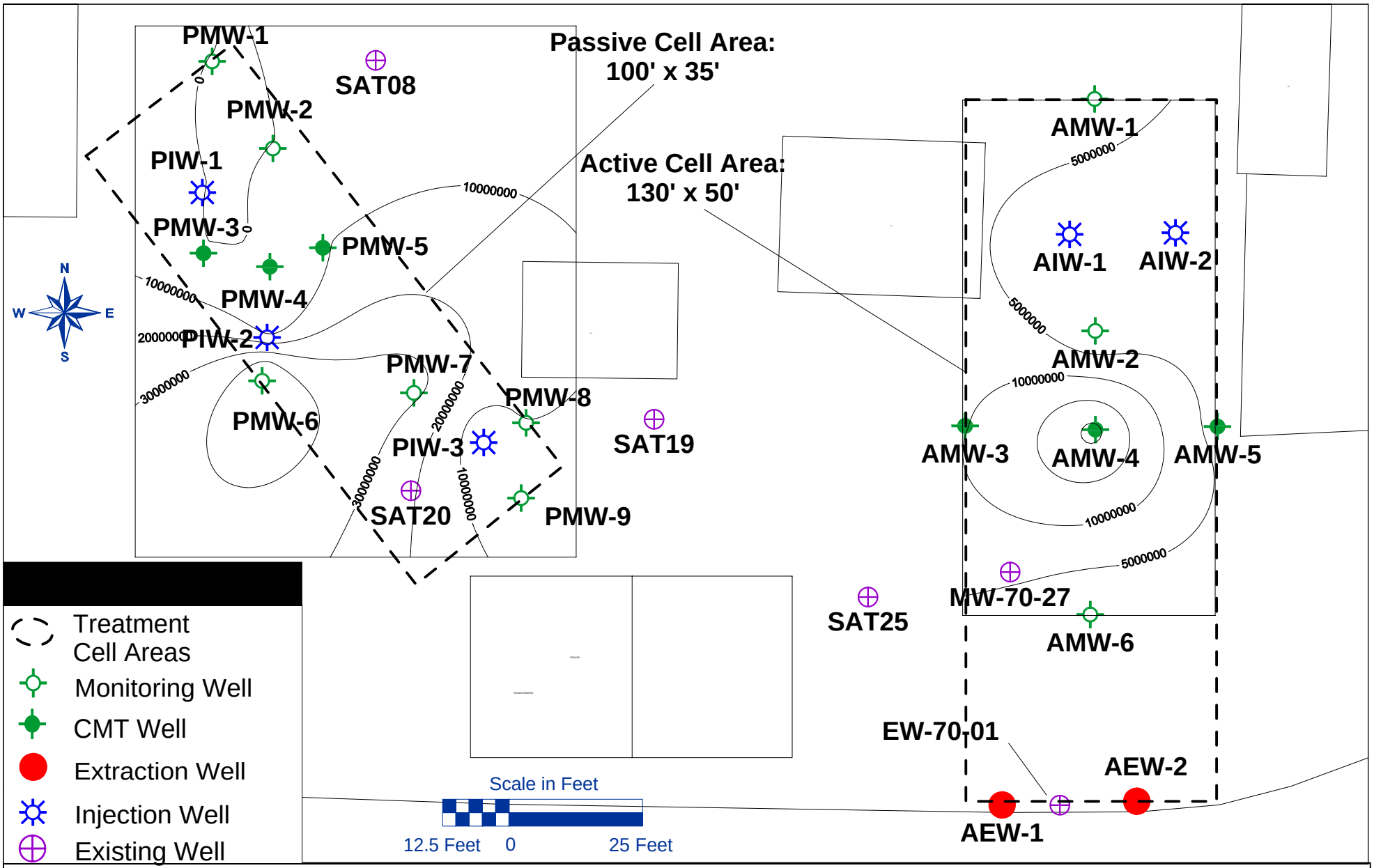


FIGURE 6-2
vcrA GENE rDNA RESULTS, OCTOBER 2009
ER-0513 FINAL REPORT
SEAL BEACH NAVAL WEAPONS STATION, SEAL BEACH, CA

CDM

Table 6-1. Active Cell Tracer Test Data

Well	Distances from Nearest Injection Well (ft)	Tracer First Arrival Date	Travel Time based on tracer first arrival (days)	Velocity based on tracer first arrival (ft/day)	Tracer Peak Arrival Date	Travel Time based on tracer peak arrival (days)	Velocity based on tracer peak arrival (ft/day)	Date of First Arrival of Bacteria	First Arrival of Bacteria (days)	"Velocity" of Bacteria (ft/d)	Retardation of Bacteria - Based on tracer peak arrival	Retardation of Bacteria - Based on tracer first arrival
AMW-2	18.0	4/16/2008	6	3.00	4/24/2008	14	1.29	1/29/2009	17	1.06	1.21	2.83
AMW-3 Z1	36.0	5/19/2008	39	0.92	6/2/2008	53	0.68	2/24/2009	43	0.84	0.81	1.10
AMW-4 Z1	36.0	4/25/2008	15	2.40	5/9/2008	29	1.24	1/29/2009	17	2.12	0.59	1.13
AMW-5 Z1	36.0	5/19/2008	39	0.92	6/2/2008	53	0.68	2/24/2009	43	0.84	0.81	1.10
			Average	1.81		Average	0.97			Average	0.86	1.54
										Std Dev	0.26	0.86

Distances from AMW-1/2

Tracer Injection performed on 4/10/08

Bioaugmentation performed on 1/12/09

The distances from injection wells presented in Table 6-1 are south from AIW-1 and AIW-2 (refer to Figure 5-1 for well locations). No corrections in distance are made for the fact that AMW-3 and AMW-4 are slightly off the axis of the treatment cell. The first tracer arrival was the first measured iodide concentration above 4 mg/L, which was the highest iodide reading during baseline sampling (before tracer was injected). The peak tracer arrival was the date of the maximum concentration of tracer at those locations where it was detected.

For *DHC* data, the date of first arrival represents the first detection of *DHC* as indicated by a *vcrA* concentration that was greater than the reporting limit. *vcrA* was used rather than the 16s rRNA because *vcrA* was determined to be the best biomarker for the bioaugmentation culture; based on the results of the pre-conditioning phase, it was possible that *DHC* increases as measured by the 16s rRNA results could occur from biostimulation alone.

The retardation of bacteria was initially calculated based on the velocity derived from the peak tracer arrival, and the first arrival of *DHC* bacteria. The peak tracer arrival was used because it represents the average linear groundwater velocity (i.e., Darcy velocity divided by effective porosity). However, from Table 6-1, *DHC* arrival was faster than peak tracer arrival for 3 of the 4 wells for which the analysis was performed. The average retardation using this method was 0.86, with a standard deviation of 0.26.

The travel time of first arrival of *DHC* was also compared to the first arrival of tracer. From Table 6-1, the average retardation of *DHC* using this method was 1.54, with a standard deviation of 0.86. The arrival of *DHC* was nearly 3 times longer than first tracer arrival for well AMW-2, but was only a few days longer for all 3 CMT wells.

The apparently very low retardation of *DHC* as shown by the CMT well results could be a result of several factors other than truly having such low retardation. The first possible factor was sampling methods. The CMT is able to target discrete zones and could detect arrival of *DHC* faster than a conventional well (AMW-2), which would be subject to dilution. However, such dilution would also have affected the tracer sampling, and therefore would not cause "false negatives" for *DHC* but not for tracer. Another possible reason for the minimal *DHC* retardation at the CMT wells relative to AMW-2 is that actual growth of *DHC* bacteria was a more significant factor in distribution to the CMT wells compared to AMW-2. This could explain the minimal retardation seen at AMW-3 and AMW-5, because *DHC* arrival was detected at 43 days, which is sufficient time for *DHC* to grow in situ. However, *DHC* was detected at both AMW-2 and AMW-4 at the first sampling event (17 days following bioaugmentation), during which time significant growth of *DHC* is unlikely. The final factor that could have contributed to the minimal *DHC* retardation is the sampling frequency for tracer didn't allow for a precise assessment of first arrival, and that tracer actually arrived sooner than it was detected. However, all three CMT wells were sampled 3 days before first arrival of tracer occurred, and in all cases the iodide concentration was less than the baseline concentrations. Because of this, the earliest that tracer could have arrived at these wells was two days earlier, which would have only had a minimal impact on the *DHC* retardation factor.

Overall, the results from the active cell indicate that minimal retardation of *DHC* bacteria occurred compared to transport of conservative tracer. In terms of actual velocity, based on the

distance from injection to monitoring wells, the average *DHC* "velocity" was 1.21 ft/day. During the active cell tracer test, the groundwater velocity was estimated to be 1-2 ft/day. Based on the actual tracer arrival, groundwater velocity using first arrival of tracer was 1.81 ft/d, while peak arrival yields a velocity of 0.97 ft/d. This implies that the *DHC* "velocity" was approximately the same as the actual groundwater velocity. Work published previous to this demonstration, suggested that retardation factors of *DHC* under forced advection could be as high as 60-200 (Major et al, 2002). However, groundwater velocity for that study was much higher under the forced gradient (greater than 25 ft /d) than the current demonstration, which suggests that the increased retardation occurs only at high groundwater velocities (at least greater than 2 ft/d).

6.3.1.2 Passive Cell Distribution

Table 6-2 shows details for tracer arrival and first detection of *DHC* for the passive treatment cell. Data are presented only for wells that were sampled monthly for *DHC* bacteria. While tracer samples were collected more frequently for the passive cell CMT wells, *DHC* data were collected monthly from the deepest CMT port (Zone 1), and approximately quarterly from all other CMT ports. Because of this, the analysis of tracer and *DHC* arrival was only performed for Zone 1 of the CMT wells. For the passive cell, tracer injection was performed on 8/7/08, and bioaugmentation was performed on 1/13/09.

The distances from injection wells presented in Table 6-2 are relative to the nearest injection well. For PMW-1 through PMW-5, the nearest injection well was PIW-1. The direction of groundwater flow in the passive cell during operation of the active cell is to the southwest; therefore well PMW-4 is located along the axis of the treatment cell, while PMW-3 and PMW-5 are slightly off axis. PMW-2 is a crossgradient well, and PMW-1 is an upgradient well. For wells PMW-6 and PMW-7, the distances in Table 6-2 are from PIW-2, and for PMW-8 and PMW-9, the distances are from PIW-3.

As for the active cell, the first tracer arrival was the first measured iodide concentration above 4 mg/L. The peak tracer arrival was the date of the maximum concentration of tracer at those locations where it was detected. The tracer injection was designed to achieve a radius of influence of 5 feet from the injection well. Because of this, the velocity and travel time calculations in Table 6-2 assume that tracer particles had traveled 5 ft of the distance between PIW-1 and the monitoring wells at "time zero," when ambient groundwater flow was assumed to be the dominant transport mechanism.

The retardation of bacteria was calculated first based on the velocity derived from the peak tracer arrival, and the first arrival of *DHC* bacteria. The peak tracer arrival was used because it represents the average linear groundwater velocity (i.e., Darcy velocity divided by effective porosity). Because tracer injection was not performed in wells PIW-2 and PIW-3, no quantitative analysis of tracer first and peak arrival could be performed. Also, of the monitoring wells installed near these injection wells, only PMW-9 is directly downgradient of an injection well. Therefore, while travel times, distances, and time of first arrival are presented in Table 6-2 for all passive cell monitoring wells, only wells PMW-3, PMW-4, and PMW-5 are included in the retardation calculations.

Table 6-2. Passive Cell Tracer Test Data

Well	Distances from Nearest Injection Well (ft)	Tracer First Arrival Date	Travel Time based on tracer first arrival (days)	Velocity based on tracer first arrival (ft/day)	Tracer Peak Arrival Date	Travel Time based on tracer peak arrival (days)	Velocity based on tracer peak arrival (ft/day)	Date of First Arrival of Bacteria	First Arrival of Bacteria (days)	"Velocity" of Bacteria (ft/d)	Retardation of Bacteria - Based on tracer peak arrival	Retardation of Bacteria - Based on tracer first arrival
Distances from PIW-1												
PMW-2	15.6	9/5/2008	29	0.36	9/23/2008	47	0.22	3/30/2009	76	0.20	1.10	1.78
PMW-3 Z1	11.6	8/21/2008	14	0.47	11/3/2008	88	0.07	1/27/2009	14	0.83	0.09	0.57
PMW-4 Z1	19.0	9/2/2008	26	0.54	10/17/2008	71	0.20	1/27/2009	14	1.36	0.15	0.40
PMW-5 Z1	24.9	9/23/2008	47	0.42	10/17/2008	71	0.28	1/27/2009	14	1.78	0.16	0.24
										Average	0.13	0.40
										StDev	0.04	0.16
Distances from PIW-2												
PMW-6	8.1	NA	7	0.44	NA	14	0.22	2/23/2009	41	0.20	1.11	2.22
PMW-7	29.3	NA	55	0.44	NA	110	0.22	1/27/2009	14	2.09	0.11	0.21
Distances from PIW-3												
PMW-8	8.7	NA	8	0.44	NA	17	0.22	2/23/2009	41	0.21	1.03	2.07
PMW-9	12.5	NA	17	0.44	NA	34	0.22	2/23/2009	41	0.31	0.72	1.44
										0.87		

Tracer injection performed on
8/7/08
The injection was designed with a 5 ft ROI, so it is assumed that the tracer traveled 5 ft at time 0.
Red = not included in the average or standard deviation calculations

From Table 6-2, the retardation of *DHC* compared to peak tracer arrival was significantly less than 1, as the average was 0.13 with a standard deviation of 0.04. Even when compared to tracer first arrival, the retardation of *DHC* was 0.40 with a standard deviation of 0.16. This implies that the first arrival of bacteria was faster than the first arrival of tracer at all three CMT wells.

For the active cell, the same factors that could have contributed to similar observations identified for the active cell above (sampling methods, *DHC* growth, and sampling frequency) were considered for the passive cell. For the passive cell, all three wells are CMT wells, so no difference existed in sampling methods. Also, *DHC* was detected 2 weeks following inoculation, during which time significant growth of *DHC* is unlikely. In terms of sampling frequency, sampling was performed 2 weeks following both tracer injection and bioaugmentation, and first arrival both of tracer and *DHC* had already occurred at PMW-3. It is possible that tracer arrived several days sooner at this well, and that the actual retardation factor for *DHC* was greater than 1. However, PMW-3 and PMW-5 were sampled 2 weeks following tracer injection and bioaugmentation, and *DHC* was detected at significant concentrations (10^5 to 10^6 cells/L), while tracer was not detected above background levels.

While the other monitoring wells were not included in the retardation analysis, it is interesting to note that arrival of *DHC* bacteria occurred at all wells within 41 days of inoculation except for PMW-2, which had *DHC* at 76 days. This represents an average "velocity" of 0.87 ft/d, which includes *DHC* transport between injection and monitoring wells off the axis of the treatment cell, and even crossgradient in some cases. For purposes of comparison, the average groundwater velocity that was calculated for the passive cell based on applying hydraulic parameters from the active cell tracer test to the passive cell was 0.25 ft/d. Based on the passive cell tracer test, the average first arrival of tracer correlates to a velocity of 0.44 ft/d, while peak arrival yields a velocity of 0.22 ft/d. This implies that the "velocity" of *DHC* is 2 to 4 times faster than that of conservative tracer. Perhaps the most important result is that bacterial transport in the passive cell was extremely rapid, with *DHC* colonization occurring at distances of up to 30 ft from injection points within two to five weeks from inoculation.

6.3.1.3 Bacterial Transport Summary

The tracer and *DHC* data indicate that bacterial transport was not significantly retarded compared to groundwater flow in either the active or passive cells. In fact, many of the calculated retardation factors were less than one, especially in the passive cell. The average retardation under passive conditions was 0.13 to 0.40 depending on whether peak or first arrival tracer data are used, and for the active cell the averages were 0.86 to 1.54. These results suggest that *DHC* were transported more rapidly relative to groundwater flow under passive conditions compared to active recirculation. The groundwater velocity in the active cell was 1 to 1.8 ft/day, and for the passive cell it was 0.22 to 0.44 ft/d. This is a contrast of approximately a factor of 5, which represents a typical enhancement in flow that might be expected due to recirculation.

Another interesting observation was the fact that bacterial transport rate and extent was relatively independent of groundwater flow direction, especially in the passive cell. The off-axis CMT wells in the active cell had *DHC* velocities that were approximately half of what was observed at wells on the axis of the treatment cell. In the passive cell, one port in PMW-3 had a *DHC* velocity that was almost the same as the average *DHC* velocity for the passive cell, and PMW-5

had a velocity that was nearly twice the average. In addition, crossgradient wells such as PMW-2, PMW-7 and PMW-8 all showed *DHC* velocities similar to that of groundwater (0.2 to 0.3 ft/d). Therefore, *DHC* transport was not only less retarded in the direction of groundwater flow at slower groundwater velocities, it also occurred more rapidly in cross-gradient directions relative to the groundwater velocity.

Overall, the *DHC* results from both treatment cells are consistent with the comparison of NAVWPNSTA Site 40 and Kelly Air Force Base in Section 2, and support the hypothesis that *DHC* bacterial transport is affected by groundwater velocity. Specifically, data from the passive cell suggest that bacterial transport was potentially faster than ambient groundwater velocity, while data from the active cells showed DHC transport was approximately the same as groundwater velocity. Work published previous to this demonstration suggested that retardation factors of DHC under forced advection could be as high as 60-200 (Major et al, 2002). However, groundwater velocity for that study was much higher under the forced gradient (greater than 25 ft/d) than the current demonstration, which suggests that the increased retardation occurs only at high groundwater velocities (at least greater than 2 ft/d). Therefore, consideration of previously published work along with results from the current demonstration suggests that retardation of bacteria decreases as groundwater velocity decreases.

6.3.1.4 Bacterial Growth

Two methods were used to assess the extent of bacterial growth. The first one was to quantify the number of *DHC* cells that were present at the end of the demonstration, and compare that to the number of cells added during bioaugmentation. Figure 6-1 shows the *DHC* counts nine months after bioaugmentation, as represented by the 16S rRNA results. In order to determine the total number of *DHC* cells in each treatment cell, the area encompassed by each *DHC* contour was calculated, and was converted to a volume by multiplying by the treatment thickness of 15 ft and the porosity of 0.2. Then, the groundwater volume contained within a given *DHC* contour was multiplied by the average *DHC* concentration for that contour to determine the total number of *DHC* cells present in each specific area. Finally, the cell counts were then summed across each treatment cell. Table 6-3 shows the results of this calculation for the active cell, where 7.0×10^{14} total *DHC* cells were present at the end of the demonstration. Table 6-4 shows the results of this calculation for the passive cell, where 3.1×10^{14} total *DHC* cells were present at the end of the demonstration.

During bioaugmentation, 100 L of bioaugmentation culture was added to each treatment cell. This culture contained 5×10^{10} *DHC* cells/L, which means that 5×10^{12} total *DHC* cells were added to each treatment cell. Since both the active and passive treatment cells had *DHC* cells on the order of 10^{14} total *DHC* cells, this implies that significant growth of approximately two orders of magnitude of *DHC* was stimulated during the demonstration.

The second method to assess the extent of bacterial growth was to determine whether *DHC* levels increased after first arrival at a given monitoring well. These trends are illustrated by Figures 5-8 and 5-14 for the active and passive cells respectively. Figure 5-8 shows that *DHC* concentrations increased by 5 to 6 orders of magnitude after it was first detected. While some of the increase is likely a "breakthrough curve" as the injected culture reaches the well, this increase is also believed to imply significant growth at this monitoring location because concentrations at

Table 6-3. Active Cell *DHC* Population Data

Id	Cell/Liter	Adjusted (Cell/Liter)	Area (m2)	Depth (m)	Volume (m3)	Volume (Liter)	Adjusted Volume (20% Porosity) (Liter)	Total Cell Count
0	20,000,000.00	10,000,000.00	50.2	4.6	229.3	229,303.16	45,860.63	4.59E+11
1	20,000,000.00	30,000,000.00	186.0	4.6	850.5	850,491.27	170,098.25	5.10E+12
2	40,000,000.00	50,000,000.00	217.4	4.6	993.7	993,730.39	198,746.08	9.94E+12
3	60,000,000.00	70,000,000.00	267.3	4.6	1222.1	1,222,101.15	244,420.23	1.71E+13
4	140,000,000.00	150,000,000.00	14.7	4.6	67.0	67,025.44	13,405.09	2.01E+12
5	180,000,000.00	190,000,000.00	4.0	4.6	18.5	18,460.64	3,692.13	7.02E+11
6	180,000,000.00	190,000,000.00	0.4	4.6	2.0	2,011.85	402.37	7.65E+10
7	20,000,000.00	10,000,000.00	5.1	4.6	23.4	23,351.40	4,670.28	4.67E+10
8	20,000,000.00	30,000,000.00	32.8	4.6	150.0	149,996.76	29,999.35	9.00E+11
9	40,000,000.00	50,000,000.00	68.8	4.6	314.4	314,416.35	62,883.27	3.14E+12
10	60,000,000.00	70,000,000.00	121.3	4.6	554.6	554,638.56	110,927.71	7.76E+12
11	80,000,000.00	90,000,000.00	615.6	4.6	2814.3	2,814,342.99	562,868.60	5.07E+13
12	100,000,000.00	110,000,000.00	421.4	4.6	1926.6	1,926,628.61	385,325.72	4.24E+13
13	120,000,000.00	130,000,000.00	395.2	4.6	1806.8	1,806,832.44	361,366.49	4.70E+13
14	140,000,000.00	150,000,000.00	274.4	4.6	1254.5	1,254,512.46	250,902.49	3.76E+13
15	160,000,000.00	170,000,000.00	213.0	4.6	973.6	973,629.31	194,725.86	3.31E+13
16	180,000,000.00	190,000,000.00	114.9	4.6	525.5	525,545.07	105,109.01	2.00E+13
17	200,000,000.00	210,000,000.00	101.6	4.6	464.5	464,536.35	92,907.27	1.95E+13
18	220,000,000.00	230,000,000.00	96.3	4.6	440.4	440,437.75	88,087.55	2.03E+13
19	240,000,000.00	250,000,000.00	93.4	4.6	427.2	427,225.82	85,445.16	2.14E+13
20	260,000,000.00	270,000,000.00	91.8	4.6	419.8	419,792.37	83,958.47	2.27E+13
21	280,000,000.00	290,000,000.00	91.0	4.6	416.1	416,128.47	83,225.69	2.41E+13
22	300,000,000.00	310,000,000.00	90.9	4.6	415.5	415,474.69	83,094.94	2.58E+13
23	320,000,000.00	330,000,000.00	91.3	4.6	417.6	417,605.05	83,521.01	2.76E+13
24	340,000,000.00	350,000,000.00	92.5	4.6	422.7	422,729.42	84,545.88	2.96E+13
25	360,000,000.00	370,000,000.00	94.4	4.6	431.5	431,521.96	86,304.39	3.19E+13
26	380,000,000.00	390,000,000.00	97.4	4.6	445.4	445,444.27	89,088.85	3.47E+13
27	400,000,000.00	410,000,000.00	102.2	4.6	467.1	467,119.17	93,423.83	3.83E+13
28	420,000,000.00	430,000,000.00	99.6	4.6	455.2	455,163.42	91,032.68	3.91E+13
29	520,000,000.00	530,000,000.00	2.1	4.6	9.8	9,776.18	1,955.24	1.04E+12
30	500,000,000.00	510,000,000.00	17.4	4.6	79.7	79,731.35	15,946.27	8.13E+12
31	480,000,000.00	490,000,000.00	36.7	4.6	167.9	167,859.28	33,571.86	1.65E+13
32	460,000,000.00	470,000,000.00	60.9	4.6	278.7	278,656.44	55,731.29	2.62E+13
33	440,000,000.00	450,000,000.00	88.4	4.6	404.2	404,215.16	80,843.03	3.64E+13
							Total *DHC* in Active Cell Area	7.0E+14

Table 6-4. Passive Cell *DHC* Population Data

Id	Cell/Liter	Adjusted (Cell/Liter)	Area (m2)	Depth (m)	Volume (m3)	Volume (Liter)	Adjusted Volume (20% Porosity) (Liter)	Total Cell Count
0	20,000,000.00	10,000,000.00	22.4	4.6	102.6	102,614.38	20,522.88	2.05E+11
1	20,000,000.00	10,000,000.00	1.0	4.6	4.4	4,394.28	878.86	8.79E+09
2	20,000,000.00	30,000,000.00	106.1	4.6	484.9	484,919.10	96,983.82	2.91E+12
3	40,000,000.00	50,000,000.00	61.2	4.6	279.8	279,846.42	55,969.28	2.80E+12
4	60,000,000.00	70,000,000.00	62.1	4.6	283.9	283,888.53	56,777.71	3.97E+12
5	80,000,000.00	90,000,000.00	60.2	4.6	275.1	275,116.72	55,023.34	4.95E+12
6	380,000,000.00	390,000,000.00	2.4	4.6	10.7	10,744.32	2,148.86	8.38E+11
7	360,000,000.00	370,000,000.00	11.6	4.6	53.1	53,087.72	10,617.54	3.93E+12
8	340,000,000.00	350,000,000.00	23.9	4.6	109.2	109,243.85	21,848.77	7.65E+12
9	320,000,000.00	330,000,000.00	37.9	4.6	173.4	173,443.09	34,688.62	1.14E+13
10	300,000,000.00	310,000,000.00	53.7	4.6	245.7	245,659.06	49,131.81	1.52E+13
11	100,000,000.00	110,000,000.00	65.3	4.6	298.5	298,529.52	59,705.90	6.57E+12
12	280,000,000.00	290,000,000.00	73.5	4.6	335.8	335,818.78	67,163.76	1.95E+13
13	260,000,000.00	270,000,000.00	115.0	4.6	525.6	525,583.87	105,116.77	2.84E+13
14	240,000,000.00	250,000,000.00	116.2	4.6	531.1	531,144.38	106,228.88	2.66E+13
15	220,000,000.00	230,000,000.00	109.8	4.6	502.1	502,093.58	100,418.72	2.31E+13
16	200,000,000.00	210,000,000.00	118.0	4.6	539.4	539,378.33	107,875.67	2.27E+13
17	120,000,000.00	130,000,000.00	77.0	4.6	351.8	351,835.82	70,367.16	9.15E+12
18	180,000,000.00	190,000,000.00	134.2	4.6	613.4	613,427.30	122,685.46	2.33E+13
19	140,000,000.00	150,000,000.00	0.1	4.6	0.3	323.54	64.71	9.71E+09
20	160,000,000.00	170,000,000.00	156.5	4.6	715.7	715,733.89	143,146.78	2.43E+13
21	140,000,000.00	150,000,000.00	177.0	4.6	809.1	809,068.41	161,813.68	2.43E+13
22	120,000,000.00	130,000,000.00	83.8	4.6	383.1	383,056.26	76,611.25	9.96E+12
23	100,000,000.00	110,000,000.00	84.4	4.6	386.0	385,981.62	77,196.32	8.49E+12
24	80,000,000.00	90,000,000.00	96.3	4.6	440.3	440,287.12	88,057.42	7.93E+12
25	60,000,000.00	70,000,000.00	115.9	4.6	529.9	529,877.98	105,975.60	7.42E+12
26	40,000,000.00	50,000,000.00	132.9	4.6	607.6	607,634.06	121,526.81	6.08E+12
27	20,000,000.00	30,000,000.00	264.3	4.6	1208.5	1,208,505.44	241,701.09	7.25E+12
28	-	10,000,000.00	648.0	4.6	2962.7	2,962,749.05	592,549.81	5.93E+12
29	-	-	421.5	4.6	1927.3	1,927,251.35	385,450.27	0.00E+00
							Total *DHC* in Passive Cell Area	3.1E+14

the inoculation points remained high the entire time, and were of a similar order of magnitude to the monitoring wells. Figure 5-14 shows a similar trend in that *DHC* concentrations increased by approximately 4 orders of magnitude at PMW-8, although concentrations did decline between the June and October 2009 sampling events.

The DNA results shown for the rest of the active and passive cell wells are provided in Appendix H and Appendix I, respectively. For both treatment cells, increases of 2 to 5 orders of magnitude of *DHC* concentrations following first arrival were observed at all locations that were monitored monthly. The CMT ports that were only monitoring quarterly had *DHC* concentrations near their maximum levels during the first sampling event following bioaugmentation. Based on data from other wells, however, most growth occurred during this initial three month period, so these data are consistent with other wells.

6.3.2 Extent of Dechlorination

The second Phase 3 objective was to assess and quantify the extent of dechlorination using both the active and passive bioaugmentation approaches. To recap the results presented in Section 5, complete dechlorination of TCE to ethene was achieved in the downgradient two-thirds of the passive treatment cell, with ethene remaining as the predominant product in PMW-7, -8, and -9 in October 2009. In PMW-6, VC and ethene combined accounted for greater than 50% of the remaining compounds. In the upper third of the cell, little dechlorination was observed in spite of having electron donor distributed to all the CMT wells; iron reduction, sulfate reduction and methanogenesis in several locations; and low to moderate numbers of *DHC*. While determining the cause of this phenomenon was beyond the scope of this demonstration, it is very possible that inhibition from co-contaminants such as chloroform could have limited *DHC* activity. Chloroform was present at concentrations as high as 1,500 µg/L and carbon tetrachloride as high as 15,000 µg/L in the passive cell near PIW-1. This is the only part of the demonstration area where these high concentrations were observed, and also the only area where complete dechlorination was not achieved.

In the active cell, complete dechlorination (as indicated by ethene production) occurred to a distance of at least 30 ft from the injection wells. By October 2009, VC and ethene were by far the predominant compounds at all locations within 30 ft of the injection wells. At 75 ft downgradient (AMW-6), degradation products were increasing at the end of the demonstration, but with no electron donor present and limited evidence of reducing conditions. This suggests that the presence of degradation products at this distance is simply due to migration from upgradient. Thus, complete dechlorination was stimulated to a distance between 30 and 75 ft.

In the ER-0513 work plan, decision rules were defined for this performance objective, based on trends observed in monitoring data as shown in Table 6-5. These decision rules are intended to provide a defined performance metric for the extent of dechlorination achieved.

Table 6-5. Decision Rules for Dechlorination Performance Objective

	Redox Conditions	Chloroethenes	Ethene	qPCR
Favorable trends	Sulfate decreasing or absent; Methane detected	Decreasing or not detected	Increasing or molar equivalent to initial TCE	*DHC* bacteria detected
Unfavorable trends	Sulfate present and not decreasing; no methane detected	Stable or increasing	Not detected	No *DHC* bacteria detected

Decision Rule 1: If the passive treatment cell shows all of the favorable trends in Table 6-5 at ≥2/3 of all monitoring wells, then it will be determined that full-scale bioaugmentation was successfully implemented using the passive approach. If less than ½ of all monitoring wells in the passive cell show all favorable trends in Table 6-5, then it will be determined that full-scale bioaugmentation was not successfully implemented using the passive approach. If more than ½ but less than 2/3 of all monitoring wells show favorable trends, then further evaluation will be required.

Decision Rule 2: If the active recirculation treatment cell shows all of the favorable trends in Table 6-5 over a distance of greater than or equal to 75 ft from the reinjection wells, then it will be determined that full-scale bioaugmentation was successfully implemented using the active recirculation approach. If the active recirculation treatment cell does not show all of the favorable trends in Table 6-5 over a distance of at least 50 ft from the reinjection wells, then it will be determined that full-scale bioaugmentation was not successfully implemented using the active recirculation approach. All other combinations of potential outcomes will require further evaluation.

Each monitoring location in both treatment cells was assessed in order to determine whether favorable trends were achieved. Table 6-6 shows the results of this analysis for the passive cell. A "Y' in Table 6-6 indicates that a favorable trend was observed at a given monitoring location for a given parameter, and an "N" means that an unfavorable trend was observed. From Table 6-6, favorable trends were observed for more than 2/3 of all passive cell monitoring locations for redox conditions, chloroethene concentrations, and qPCR results. However, ethene production was only measured at half of the monitoring locations, and at some of these concentrations were between 5 and 10 µg/L. In addition, concentrations of TCE decreased at some locations without a corresponding increase in daughter products.

Based on Decision Rule 1, between ½ and 2/3 of all monitoring wells in the passive cell exhibited favorable trends for all four parameters. According to Decision Rule 1, this condition requires further evaluation. As discussed above, it is possible that high concentrations of chloroform limited *DHC* activity. Regardless of the cause of the inhibition, even though only half of the monitoring wells showed ethene production, this number is biased because all of these wells are located near PIW-1. In terms of treatment cell area, ethene production was observed in the passive cell near two of the three injection wells. This implies that dechlorination to ethene was observed throughout approximately two-thirds of the passive cell. Therefore, this performance objective was met in terms of area for the passive cell, though not in terms of monitoring wells.

Table 6-6. Passive Cell Results for Dechlorination Performance Objective

Well	PIW -1	PIW -2	PIW -3	PMW -1	PMW -2	PMW -3 (Z1)	PMW -3 (Z2)	PMW -3 (Z3)	PMW -4 (Z1)	PMW -4 (Z3)	PMW -4 (Z4)	PMW -5 (Z1)	PMW -5 (Z2)	PMW -5 (Z3)	PMW -6	PMW -7	PMW -8	PMW -9	Total Y
Redox Conditions	N	Y	Y	Y	Y	N	Y	N	Y	Y	Y	Y	Y	N	Y	Y	Y	Y	0.78
Chloroethenes	Y	Y	Y	N	N	N	Y	Y	Y	Y	N	Y	Y	Y	Y	Y	Y	Y	0.78
Ethene	Y	Y	Y	N	N	N	N	N	Y	N	N	Y	N	N	Y	Y	Y	Y	0.50
qPCR	Y	Y	Y	Y	Y	Y	Y	N	Y	Y	N	Y	Y	N	Y	Y	Y	Y	0.83

Notes:
Y - Favorable trends observed
N - Favorable trends not observed

Table 6-7 shows the results of the extent of dechlorination analysis for the active cell. From Table 6-7, favorable trends were observed everywhere except AMW-6 and the extraction wells. Based on data presented in Section 5, AMW-6 and the extraction wells were beyond the area that was impacted by lactate injections and bioaugmentation, so these results are expected.

While more than 2/3 of the monitoring wells showed favorable trends in the active cell, Decision Rule 2 was based on the distance from the injection wells that was impacted. All wells that exhibited favorable trends are within 36 ft of the injection wells. Therefore, the portion of the active cell with favorable trends extends somewhere beyond 36 ft, but is less than 75 ft, which is the distance to the next well (AMW-6). According to Decision Rule 2 in Table 6-5, these results require further evaluation. Since too many utilities were present at the site in order to install any monitoring wells between 36 ft and 75 ft from the injection points, the precise location of the area that was impacted by the demonstration is unknown. Because of this, it was determined that this performance objective was partially met for the active cell.

Overall then, this performance objective was partially met. What is more important, however, is that the data are more than sufficient to make a comparison of the relative pros and cons of the two bioaugmentation strategies, which is discussed in the next section.

6.3.3 Comparison of Performance of Active and Passive Approaches

A third decision was identified in the Demonstration Plan: to determine whether, and to the extent possible, under what conditions the passive approach is more technically effective and cost effective than the active recirculation approach. Decision #3 is based on the outcomes of Decisions 1 and 2, as well as on cost. Because of the multiple combinations of outcomes, and because of the fact that Decision Rules 1 and 2 are qualitative and are based on trends rather than explicit action levels, no decision rule was presented for Decision #3. However, an overall evaluation is made considering all available data in order to determine whether the passive approach was more technically effective and more cost effective than the active approach. Costs are discussed in Section 7, and technical performance is summarized below.

Table 6-7. Active Cell Results for Dechlorination Performance Objective

Well	AMW-1	AMW-2	AMW-3 (Z1)	AMW-3 (Z2)	AMW-3 (Z3)	AMW-4 (Z1)	AMW-4 (Z2)	AMW-4 (Z3)	AMW-5 (Z1)	AMW-5 (Z2)	AMW-6	AEW	Total Y
Redox Conditions	Y	Y	Y	Y	Y	Y	Y	Y	N	Y	N	N	0.75
Chloroethenes	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	N	0.83
Ethene	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	N	0.83
qPCR	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	N	0.83

Notes:
Y - Favorable trends observed

N - Favorable trends not observed

Based on all data for both the active and passive treatment cells, the following conclusions can be made regarding technical performance of the demonstration:

- Electron donor distribution from an individual injection point was similar using both the passive and active approaches (greater than 25 ft in both cases)
- Electron donor and *DHC* distribution varied vertically for both strategies based on data from the CMT wells; this did not have a negative impact on dechlorination in the active cell, but dechlorination was minimal in all the CMT wells in the passive cell (likely due to inhibition caused by co-contaminants)
- Higher electron donor concentrations were achieved in the passive cell, which required significantly less donor compared to the active approach
- Strongly reducing redox conditions were established within similar timeframes using both approaches
- Dechlorination performance was similar for both approaches, with the exception of possible inhibition in part of the passive cell
- Bacterial distribution was similar from a given injection location both in terms of time to first arrival, and in terms of area influenced
- In terms of area impacted, the passive approach stimulated dechlorination and bacterial distribution over a larger percentage of the treatment cell compared to the active approach, which was limited to the area near the injection wells

It is likely that the hydrogeology of this site played an important role in the similar technical performance of the passive and active bioaugmentation strategies. In particular, it was observed that *DHC* was transported rapidly in both scenarios, with first arrival of *DHC* showing little or no retardation compared to first arrival of a conservative tracer. In addition, these first arrivals revealed the presence of some relatively high-flow solute transport pathways in the subsurface. It is possible that having some such higher-velocity flow paths is an important ingredient for the success of a passive bioaugmentation strategy. Without such paths, DHC transport might be slowed significantly. It is possible that an active strategy might achieve more rapid DHC transport in a hydrogeologic setting with uniformly slow solute transport, though that could not be evaluated in this demonstration. A tracer test is a useful characterization technique for any full-scale bioaugmentation application to assist not only in the selection of a passive vs. an active approach, but also for design of injection well spacing, placement of well screens, monitoring well locations, and so forth. Tracer testing with three-dimensional monitoring, as with CMT wells, is particularly useful for this purpose, as was also illustrated and documented in the final reports for ESTCP project ER-0218.

Overall, technical performance of both approaches was similar in all regards. However, as discussed in Section 6.4, operations and maintenance (O&M) requirements were higher for the active approach, and the system was not as user-friendly compared to the passive approach. Also, as presented in Section 7, costs for the active approach were higher than for the passive approach.

6.4 QUALITATIVE PERFORMANCE OBJECTIVES

One qualitative performance objective was established for the ER-0513 project. This objective was to assess the ease of use for both passive and active approaches. This includes operational time required in the field, time spent conducting maintenance and repair activities, and the amount of training required to operate each system. Data collected in support of this objective include feedback from field personnel; injection and operational logs, and the field team leader logbook.

During the course of the demonstration, the active recirculation system required more time for troubleshooting and maintenance than the passive system did. One major shutdown occurred in late 2008 due to malfunction of overflow shutoff switches and the autodialer (refer to Section 5.6.3). This required modification of the recirculation system to include an additional overflow tank, and additional instrumentation. In addition, several minor equipment malfunctions occurred during the course of the demonstration, such as flowmeter clogging, temporary extraction pump shutdowns, and PLC errors. The active recirculation system also required more training for field personnel to understand the PLC programming, how to properly dose the electron donor, and how to troubleshoot the system. Although it did not occur during this demonstration, it is our experience from working at other sites that biofouling is also more common in recirculation systems than passive injection systems.

In contrast, the passive system required no electronics, and only had one minor repair to replace flowmeters. Less training was required for the passive system, because it consisted of a simple manifold to inject three wells at a time. The passive system did require a source of potable water to use for the injections, but one was available nearby.

The success criterion for this performance objective was to quantify the operational requirements for each approach. Data collected during the course of the ER-0513 demonstration did allow for an assessment of the ease of use of both approaches, and it was determined that the passive system was easier to use and required less maintenance. Therefore, this performance goal was met.

7.0 COST ASSESSMENT

A critical evaluation criterion for any cleanup technology is cost. In this section, implementation costs for bioremediation of chlorinated solvent source areas are estimated based on the costs of the demonstration. Section 7.1 includes a review of the approximate costs associated with the demonstration project. Section 7.2 provides a discussion of the primary cost drivers that influence effective implementation of EAB at sites, and includes a discussion of the positive and negative characteristics of active and passive treatment methods demonstrated for this project. Finally, Section 7.3 provides cost information for successful implementation of the remedy at a theoretical site.

7.1 COST REPORTING

Table 7-1 provides the estimated implementation costs of the technology for the Site 70 demonstration project at NAVWPNSTA Site 70. These costs are the approximate costs for performing a detailed demonstration of the technology, including more intensive sampling and analysis than would typically be needed for a more "standard" application of the technology. Projected costs for a more typical application of the technology at a model site are provided in Section 7.3.

Detailed discussions of each of the cost element tasks in the table have been provided in previous sections of this report. For clarity, a summary of each is provided below:

Start-up: consists of work plan development and treatability/DNA sequencing studies. Work plan development included finalization of the demonstration design, negotiation of anticipated project activities and costs, and development of supporting documentation. The treatability study consisted of bench-scale testing for dechlorination, which was recommended due to the high sulfate and chloride concentrations present at the site. The DNA sequencing study was conducted to determine whether native species of *DHC* were present at the site prior to implementation of the demonstration. Presence of the bacteria could have impacted the ability to assess growth and distribution of the bioaugmentation culture during the demonstration project.

General Construction: consists of well installation, tracer testing and hydraulic characterization, and groundwater modeling. Well installation included monitoring, extraction, and injection well installation that was necessary for completion of the demonstration. Tracer testing and hydraulic characterization was performed to gather data on flow characteristics within the active and passive treatment cells. Modeling work was performed to indicate potential groundwater extraction rates and to anticipate electron donor distribution in the subsurface.

Active Cell Construction: consists of injection system construction, lactate injections, bioaugmentation, system troubleshooting/maintenance, and sampling. The active cell was constructed to include groundwater extraction and reinjection components, and to facilitate injection of electron donor for bioremediation. Bioaugmentation was necessary to provide *DHC* with the *vcrA* gene, which is necessary to obtain complete dechlorination to ethene. General system troubleshooting and maintenance was necessary for upkeep of the treatment system. Sampling was included for evaluation of the system performance.

Table 7-1. Approximate Implementation Costs for EAB at NAVWPNSTA Site 70

Cost Element	Sub-Category	Detail	Costs
Start-Up Costs			**$100,000**
	Treatability/DNA Sequencing Study	Procurement- 80 hr	$6,000
		Subcontractors (lab services)	$20,000
	Work Plan	Project Manager- 220 hr	$27,500
		Technical Reviewer- 40 hr	$8,000
		Project Engineer- 340 hr	$34,000
		Drafting/Clerical- 60 hr	$4,500
General Construction Costs			**$214,200**
	Well Installation/Development	Project Geologist- 500 hr	$50,000
		Subcontractor	$112,000
		Materials/ODCs	$20,000
	Tracer Testing/Hydraulic Characterization	Project Manager - 40 hr	$5,000
		Project Engineer - 40 hr	$4,000
		Project Geologist - 160 hr	$16,000
		Materials/ODCs	$4,200
	Screening Level Groundwater Modeling	Project Hydrogeologist - 24 hr	$3,000
Active Cell Construction/ O&M			**$341,300**
	Oversight/Supervision	Project Manager - 200 hr	$25,000
	Lactate Injection System Purchase/ Construction	Subcontractor	$40,000
	Lactate Injection (1x per week)	Project Engineer- 10 hr/event, 40 events	$40,000
		Lactate- 50 gal per event, 40 events	$24,000
	Bioaugmentation	Project Engineer- 20 hr	$2,000
		Bacterial Culture	$15,000
	System Troubleshooting/ Maintenance (1 major and 3 minor events during demo)	Project Engineer - 80 hr	$8,000
		Technician - 80 hr	$4,800
		Materials/ODCs	$10,000
	Sampling (12 total events)	Project Engineer - 240 hr	$24,000
		Project Geologist - 240 hr	$24,000
		Analytical (all analytes, including CSIA and qPCR)	$106,500
		Materials/ODCs ($1,500 per event)	$18,000

Cost Element	Sub-Category	Detail	Costs
Passive Cell Construction/ O&M			**$251,300**
	Oversight/Supervision	Project Manager - 100 hr	$12,500
	Lactate Injection System Purchase/ Construction	Subcontractor	$15,500
	Lactate Injection (1x per week)	Project Engineer- 20 hr/event, 12 events	$24,000
		Lactate- 50 gal per event, 12 events	$7,200
	Bioaugmentation	Project Engineer- 20 hr	$2,000
		Bacterial Culture	$15,000
	System Troubleshooting/ Maintenance (1 minor event during demo)	Project Engineer - 10 hr	$1,000
		Technician - 10 hr	$600
		Materials/ODCs	$1,000
	Sampling (12 total events)	Project Engineer - 240 hr	$24,000
		Project Geologist - 240 hr	$24,000
		Analytical (all analytes, including CSIA and qPCR	$106,500
		Materials/ODCs ($1,500 per event)	$18,000
Performance Assessment, Reporting, and Project Management			**$210,000**
	Includes final project reports, tech transfer, and data management/interpretation	Project Manager- 600 hr	$75,000
		Technical Reviewer- 200 hr	$40,000
		Project Engineer- 600 hr	$60,000
		Drafting/Clerical- 200 hr	$15,000
		Travel/ODC's	$20,000
Demobilization	Site Cleanup and Restoration		**$5,000**
Waste Disposal			NA
Long-term Monitoring			NA

Passive Cell Construction: similar to the active cell construction, with the exception of groundwater extraction and reinjection. The passive cell did not include these components, and utilized natural groundwater flow to distribute electron donor and bacteria. The costs for passive cell construction and O&M were considerably less than the active cell.

Performance Assessment, Reporting, and Project Management: includes ongoing management and review of analytical data, as well as periodic project reporting. This also includes preparation of the final project reports.

Demobilization: includes removing equipment and materials from the site, as well as site restoration.

Waste Disposal: Includes removal and disposal of all investigation derived waste. These costs are standard, fairly insignificant, and were not tracked during the demonstration.

Long-Term Monitoring: Includes monitoring conducted after the demonstration is completed. These costs are standard and were not tracked during the demonstration.

7.2 COST DRIVERS

As with most *in situ* remediation technologies, the most important aspect of implementing bioaugmentation in chlorinated solvent source areas is delivery and distribution. That is, the electron donor and bacteria must be distributed throughout the target treatment zone to stimulate the desired degradation. Therefore, the major cost drivers are likely to be the infrastructure and materials required to achieve distribution of amendments. These are largely driven by the scale of a site laterally and vertically, as well as the hydraulic conductivity and the degree of heterogeneity. The "bulk" hydraulic conductivity of the treatment zone will determine the spacing of injection wells, and will have a strong influence on the required treatment duration. The heterogeneity will mostly impact the treatment duration because a high degree of heterogeneity will increase the potential for preferential flow. A high degree of preferential flow will result in a cleanup timeframe that is dependent upon diffusion more than advection, which will increase treatment duration, thereby increasing costs.

Similarly, the sheer mass of contamination can be a cost driver. As long as the source consists primarily of solvents at residual saturation or sorbed to the soil, mass removal can be fairly rapid (subject to the potential constraints of hydraulic conductivity and heterogeneity discussed above). However, if DNAPL is present in pools, the cleanup timeframe becomes limited by dissolution rates. While these rates can be accelerated during bioremediation (see the ER-0218 final report), cleanup timeframes will still be long for large pools of DNAPL.

Another potential cost driver is a need for hydraulic containment. If a sufficient downgradient buffer zone is not available at a site and extraction of groundwater is required to prevent the temporary increase in mass flux caused by EAB from impacting some nearby downgradient receptor, costs would increase. This is especially true if for some reason the extracted water cannot simply be reinjected in the source area.

Vapor intrusion concerns can also be a potential cost driver. Bioremediation of chlorinated solvents via EAB generates VC and methane. For shallow, unconfined groundwater sites, this creates the potential for these gases to reach fairly high concentrations in the unsaturated zone above the water table. If potential receptors were present above the treatment zone and soil vapor extraction were required, this would increase technology costs.

7.3 COST ANALYSIS

This section provides an estimate for "typical" passive and active bioaugmentation approaches at an example site with similar characteristics to that of NAVWPNSTA Site 70. The estimate is based on the costs associated with the demonstration project, but does not include the level of rigor required for technology validation. Table 7.2 provides the site characteristics and assumptions for the example site.

Table 7-2. Parameters Used as the Basis for Calculating Technology Implementation Costs.

	Active Approach	Passive Approach
Site Area (acre)	0.5	0.5
Site Area (sq ft)	21,780	21,780
Contaminated Thickness Treated (ft)	20	20
Treatment Volume (cubic yards)	16,200	16,200
Number of Injection Wells (scaled up from demonstration)	10	19
Number of Multilevel Monitoring Wells	2	2
Number of Fully Penetrating Monitoring Wells	8	8
Number of Extraction Wells (active cell only)	10	0
Duration of Operations (years)	5	5
Frequency/Concentration of Electron Donor Injection	Weekly/(3%)	Monthly (1%)
Frequency of Monitoring Events	quarterly	quarterly
Monitoring Analytes	Same as Demonstration, but no CSIA and DNA only for first year	Same as Demonstration, but no CSIA and DNA only for first year

An effort was made to be conservative in several of the parameters so as to avoid being too optimistic in the estimate. For example, the number of monitoring wells (especially the multilevel wells) is higher than many cleanups at the assumed scale. In addition, the Site 70 costs included tracer testing, modeling, a treatability study, and DNA sequencing, as noted in Table 7-1. These activities are not always performed in typical applications, but can significantly improve technology performance, and should be considered prior to implementation of a remedy. The tracer testing and modeling efforts could be especially beneficial to a similar project, as they may aid in determination of flow rates, donor distribution effectiveness, estimated cleanup timeframes, and whether a passive or active treatment method would be more appropriate.

In other cases, the demonstration costs were reduced to reflect, for example, the frequency of sampling that would be typical of implementation, as opposed to the frequent sampling required to quantify bacterial growth and distribution under different conditions. Also, this project included two separate drilling mobilizations in order to properly construct both treatment cells; this would not be required for a typical implementation.

The number of injection wells required for each approach was scaled up based on the ER-0513 project. For the active approach, this was based on the fact that approximately one-half to two-thirds of the treatment cell was impacted during the demonstration, using two extraction and two injection wells. For the theoretical site, this led to 10 injection and extraction wells for the active approach, and 19 injection wells for the passive approach. The same lactate injection frequency was assumed for each approach (weekly for active, and monthly for passive). Monitoring would be conducted quarterly, rather than monthly as was done during the demonstration. Also, CSIA would not be performed, and qPCR for *DHC* would only be performed during the first year of operations.

This cost analysis focuses on comparing and contrasting the passive and active approaches for bioaugmentation in the context of implementing bioremediation for cleanup of a chlorinated solvent source area. For a comparison of bioremediation to other remediation technologies for source area cleanup, see the Cost and Performance Report for ESTCP project ER-0218.

Life cycle costing provides the greatest utility when a project has a significant initial capital or short-term operating cost, followed by a much longer period of lower operating costs. This is not really the case either for the comparison of active and passive bioaugmentation approaches (in any case, they would be assumed to have the same long-term monitoring needs if that were included). For both cases, the costs were assumed to be incurred over 5-6 years (including preliminary characterization, well drilling, etc.). Thus, the total costs reported below essentially are the life cycle costs. In both cases, the capital cost is relatively small and the operational period is still not very long, so again the utility of a net present value calculation is minimal and was not performed.

Tables 7-3 and 7-4 present the projected implementation costs for bioaugmentation using the active and passive approach, respectively. Most of the costs are similar (e.g. start-up, general construction, monitoring, and performance assessment) because they are common to both active and passive approaches. However, for a theoretical site of this size, the construction and O&M costs for the active approach are approximately three times as high as for the passive approach. The result is an estimated cost for the active approach of $2.5 M, compared to $1.5M for the passive approach. The primary drivers for this cost increase are the significantly higher amount of lactate required, and the higher costs for maintenance and oversight of recirculation systems. The magnitude of the cost differences for O&M activities increases as the size of the area treated increases. As alluded to in Section 6, the benefits of implementing an active approach do not appear to be justified by the increased costs, at least for a site like NAVWPNSTA Seal Beach. Bacterial distribution was not significantly faster, and dechlorination performance was similar to the passive approach.

It should be noted that some sites might have conditions that would lead to more significant benefits for recirculation systems. For sites with very high groundwater flow velocities, recirculation might be needed to manage residence within the treatment zone avoid chlorinated degradation products migrating off-site. Such a site would also allow electron donor to be distributed over a much larger distance prior to being degraded than was possible at Seal Beach, which would increase the benefit.

Table 7-3. Projected Implementation Costs for Bioaugmentation using Active Recirculation Approach

Cost Element	Sub-Category	Detail	Costs
Start-Up Costs			**$100,000**
	Treatability/DNA Sequencing Study	Procurement- 80 hr	$6,000
		Subcontractors (lab services)	$20,000
	Work Plan	Project Manager- 220 hr	$27,500
		Technical Reviewer- 40 hr	$8,000
		Project Engineer- 340 hr	$34,000
		Drafting/Clerical- 60 hr	$4,500
General Construction Costs			**$201,700**
	Well Installation/Development	Project Geologist- 500 hr	$50,000
		Subcontractor	$112,000
		Materials/ODCs	$20,000
	Tracer Testing/Hydraulic Characterization	Project Manager - 20 hr	$2,500
		Project Engineer - 20 hr	$2,000
		Project Geologist - 80 hr	$8,000
		Materials/ODCs	$4,200
	Screening Level Groundwater Modeling	Project Hydrogeologist - 24 hr	$3,000
Active Approach Construction/ O&M			**$1,751,700**
	Oversight/Supervision	Project Manager - 800 hr	$100,000
	Lactate Injection System Purchase/ Construction	Subcontractor	$160,000
	Lactate Injection (1x every week)	Project Engineer- 10 hr/event, 260 events	$260,000
		Lactate- 250 gal per event, 260 events	$780,000
	Bioaugmentation	Project Engineer- 80 hr	$8,000
		Bacterial Culture	$60,000
	System Troubleshooting/ Maintenance (1 major and 3 minor events during demo)	Project Engineer - 320 hr	$32,000
		Technician - 320 hr	$19,200
		Materials/ODCs	$40,000
	Sampling (21 total events)	Project Engineer - 630 hr	$63,000
		Project Geologist - 630 hr	$63,000
		Analytical (all analytes, excluding CSIA and qPCR only for Year 1)	$135,000
		Materials/ODCs ($1,500 per event)	$31,500

Cost Element	Sub-Category	Detail	Costs
Performance Assessment, Reporting, and Project Management			**$420,000**
	Includes final project reports, tech transfer, and data management/interpretation	Project Manager- 1200 hr	$150,000
		Technical Reviewer- 400 hr	$80,000
		Project Engineer- 1200 hr	$120,000
		Drafting/Clerical- 400 hr	$30,000
		Travel/ODC's	$40,000
Demobilization	Site Cleanup and Restoration		**$20,000**
Waste Disposal			NA
Long-term Monitoring			NA
Total			**$2,493,400**

On the other hand, sites with very low groundwater velocities might make a passive system impractical because very little distribution can be achieved without enhancing the hydraulic gradient. What this demonstration indicates is that for sites that are closer to the "average" in terms of groundwater velocity, passive bioaugmentation systems are likely to be more cost-effective than active systems.

Table 7-4. Projected Implementation Costs for Bioaugmentation using Passive Approach

Cost Element	Sub-Category	Detail	Costs
Start-Up Costs			**$100,000**
	Treatability/DNA Sequencing Study	Procurement- 80 hr	$6,000
		Subcontractors (lab services)	$20,000
	Work Plan	Project Manager- 220 hr	$27,500
		Technical Reviewer- 40 hr	$8,000
		Project Engineer- 340 hr	$34,000
		Drafting/Clerical- 60 hr	$4,500
General Construction Costs			**$201,700**
	Well Installation/Development	Project Geologist- 500 hr	$50,000
		Subcontractor	$112,000
		Materials/ODCs	$20,000
	Tracer Testing/Hydraulic Characterization	Project Manager - 20 hr	$2,500
		Project Engineer - 20 hr	$2,000
		Project Geologist - 80 hr	$8,000
		Materials/ODCs	$4,200
	Screening Level Groundwater Modeling	Project Hydrogeologist - 24 hr	$3,000
Passive Approach Construction/ O&M			**$761,300**
	Oversight/Supervision	Project Manager - 400 hr	$50,000
	Lactate Injection System Purchase/ Construction	Subcontractor	$62,000
	Lactate Injection (1x every week)	Project Engineer- 20 hr/event, 48 events	$96,000
		Lactate- 317 gal per event, 48 events	$182,400
	Bioaugmentation	Project Engineer- 80 hr	$8,000
		Bacterial Culture	$60,000
	System Troubleshooting/ Maintenance (1 major and 3 minor events during demo)	Project Engineer - 40 hr	$4,000
		Technician - 40 hr	$2,400
		Materials/ODCs	$4,000
	Sampling (21 total events)	Project Engineer - 630 hr	$63,000
		Project Geologist - 630 hr	$63,000
		Analytical (all analytes, excluding CSIA and qPCR only for Year 1)	$135,000
		Materials/ODCs ($1,500 per event)	$31,500

Cost Element	Sub-Category	Detail	Costs
Performance Assessment, Reporting, and Project Management			**$420,000**
	Includes final project reports, tech transfer, and data management/interpretation	Project Manager- 1200 hr	$150,000
		Technical Reviewer- 400 hr	$80,000
		Project Engineer- 1200 hr	$120,000
		Drafting/Clerical- 400 hr	$30,000
		Travel/ODC's	$40,000
Demobilization	Site Cleanup and Restoration		**$20,000**
Waste Disposal			NA
Long-term Monitoring			NA
Total			**$1,503,000**

8.0 IMPLEMENTATION ISSUES

This section discusses implementation issues for bioaugmentation. In general, the issues are similar when using either the passive or active approach. However, additional issues related to permitting may be encountered when applying the technology using the active recirculation approach.

8.1 REGULATIONS THAT APPLY TO BIOAUGMENTATION

The primary regulation or set of regulations that are applicable to bioaugmentation technology are related to underground injection control. Permits may be required for both electron donors and for bioaugmentation cultures. Specifically in California, Waste Discharge Requirement (WDR) permits are required. General WDR permit NO. R4-2007-0019 covers groundwater remediation at petroleum hydrocarbon fuel, VOC, and/or hexavalent chromium impacted sites. Any amendment listed in this permit can be used at a site without a separate permitting process. In cases where a general WDR permit does not cover the amendments or cultures required for a site, a site-specific WDR permit may be needed. It should be noted that permits are not required for remediation at CERCLA sites such as NAVWPNSTA Site 70; however the substantive requirements of the permits need to be met.

Bioaugmentation at sites that use recirculation also need to address the issue of how extracted water is handled. Some states may have regulations that state extracted water needs to be treated prior to reinjection. However, RCRA regulations [specifically 3020(b)] specifically allow for both injection of treatment agents, and reinjection of extracted water amended with bioremediation treatment agents if certain conditions are met: "Specifically, the groundwater must be treated prior to reinjection; the treatment must be intended to substantially reduce hazardous constituents in the ground water – either before or after reinjection; the cleanup must be protective of human health and the environment; and the injection must be part of a response action under CERCLA, Section 104 or 106, or a RCRA corrective action intended to clean up the contamination."

8.2 STAKEHOLDER/END-USER ISSUES

While bioaugmentation is an innovative technology that has not been extensively documented at full scale, *in situ* bioremediation has been implemented at many DoD sites across the country. In general, *in situ* bioremediation is well received by regulators and the public for many reasons, including:

- **Low Risks** – Since most or all of the contaminant treatment occurs in the soil or groundwater, risks to human health and the environment during implementation are low compared to *ex situ* technologies.
- **Low secondary waste generation –** Contaminant treatment occurs *in situ*, with little offsite disposal of residuals required.
- **Minimal impacts during operations –** Compared to *ex situ* technologies, little infrastructure is required to implement and operate the bioremediation systems, resulting in minimal disruption to businesses and residences.

- **Overall risk reduction** – *In situ* bioremediation has been shown to be reliable in significantly decreasing contaminant concentrations in relatively short timeframes, resulting in reductions of risk to human health and the environment.

While the merits of bioremediation have resulted in widespread acceptance of the technology, full-scale bioaugmentation does present issues that are not encountered for bioremediation alone. These issues can be categorized as either concerns about the technology itself, or decision-making factors related to implementation of the technology.

The primary concerns about full-scale bioaugmentation are related to the introduction of exogenous bacteria to a site's groundwater. Stakeholders may object to the introduction of non-native bacteria to an aquifer. For the current demonstration project, this concern was addressed by citing the precedence for performing bioaugmentation at other sites, most notably at NAVWPNSTA Seal Beach Site 40, as well as the fact that bioaugmentation is the CERCLA selected remedy for Site 70. Another concern related to the introduction of bacteria may be simply the ability to distribute them over a sufficient area to achieve full-scale treatment; this was the purpose of this demonstration project.

The primary end user decision-making factors regarding bioaugmentation are when (or if) to perform the actual inoculation events, and the most effective and efficient method for distribution of the bacteria. The first factor has been somewhat controversial within the environmental community, and the "proper" decision will depend on the specifics of the site. While this factor is not the primary focus of the demonstration project, it is important in terms of bioaugmentation implementation. At a minimum, a site should not be bioaugmented until the appropriate redox conditions have been established (i.e., sulfate reduction or methanogenesis) through biostimulation alone. Once this has been achieved, opinions vary about the amount of time to continue biostimulation before bioaugmenting. On one extreme, some advocate bioaugmenting immediately after achieving the appropriate redox conditions without waiting to see if the appropriate dechlorinating bacteria are indigenous to the site. The reasoning for this approach is that bioaugmentation will reduce lag times prior to the onset of complete dechlorination even if dechlorinating bacteria are present at the site. However, this approach could result in unnecessarily bioaugmenting a site, which could increase overall remediation costs. The other extreme for this factor is to perform biostimulation alone for months or even years in order to determine if DCE stall will eventually be overcome naturally at a site. The reasoning for this approach would be to avoid unnecessarily bioaugmenting a site when dechlorinating bacteria will eventually proliferate. The potential disadvantage of this approach is that a site could remain in a state of DCE stall for a significant amount of time before complete dechlorination is achieved, thereby increasing life-cycle costs compared to bioaugmentation.

Given that the purpose of this demonstration is to compare full-scale bioaugmentation systems (as opposed to remediation of the site), the first approach was adopted for this project. Since the pre-conditioning approach was adopted, it did provide the opportunity to sample for *DHC* bacteria and determine whether biostimulation alone would be sufficient. In this case, it was evident that bioaugmentation would be required. Another factor in favor of performing bioaugmentation as soon as redox conditions are appropriate is that the cost of bioaugmentation is usually a small portion of overall project costs, and in many cases is cost effective compared to a longer biostimulation phase. However, this does not imply that this is the approach

recommended for all sites. Very large sites, for which bioaugmentation would represent a significant cost, may benefit from a longer biostimulation phase.

The second factor, the best method for large-scale distribution of bacteria, is the primary focus of this demonstration project. The results of the side-by-side comparison of the passive and active approaches were presented in Sections 5 and 6. This topic is also discussed in the forthcoming ESTCP monograph on bioaugmentation.

8.3 PROCUREMENT ISSUES

No significant procurement issues exist for bioaugmentation. This technology uses readily available techniques for well installation, and standard components for performing substrate injections. Projects that use a recirculation approach require more equipment and above ground infrastructure, but it is all standard and readily available from industrial supply companies. Amendments are widely available from bioremediation vendors across the country, and several bioaugmentation cultures are available from multiple suppliers. Bioaugmentation technology does require somewhat specialized expertise to properly interpret data and make operational changes in order to optimize performance.

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APPENDICES

Appendix A: Points of Contact

POINT OF CONTACT Name	ORGANIZATION Name Address	Phone Fax E-mail	Role in Project
Joey Trotsky	NAVFAC ESC	(805) 982-1258	PI
Kent Sorenson	CDM	(303)-383-2300 sorensonks@cdm.com	Co-PI
Ryan Wymore	CDM	(303)-383-2300 wymorera@cdm.com	Project Manager
Brenda Reese	NAVFAC SW	(619)-532-4209	Remedial Project Manager
Pei-Fen Tamashiro	NAVWPNSTA Seal Beach	(562) 626-7897	IR Program Coordinator

Appendix B
Memoranda Submitted to ESTCP

June 6, 2008

Ms. Andrea Leeson, Ph.D.
ESTCP Program Office
901 North Stuart Street, Suite 303
Arlington, VA 22203

Subject: Baseline sampling and tracer test results for ER-0513

Dear Andrea:

This White Paper presents results of baseline sampling and tracer testing for Environmental Security Technology Certification Program (ESTCP) project ER-0513, with the intent of documenting whether the selected site will be appropriate for meeting the demonstration objectives. This project is being conducted at Naval Weapons Station Seal Beach, Site 70. The purpose of this demonstration is to compare the low-cost, passive approach for bioaugmentation to the more common recirculation approaches for full-scale TCE source area application. Performance of the two approaches is being measured in terms of growth and distribution of Dehalococcoides bacteria, time required to achieve complete dechlorination in the test area, and cost. Specifically, the technical objectives of this project are to:

- Demonstrate cost-effective large-scale bacterial distribution
- Demonstrate induction of complete dechlorination
- Compare and contrast passive and active approaches
- Provide technology transfer

Project field work began in February 2008 with construction of the active recirculation treatment cell. This was followed by the initiation of the "pre-conditioning" phase during which electron donor is being added to both the active and passive treatment cells in order to establish appropriate reducing conditions in the aquifer prior to bioaugmentation.

The active recirculation cell extracts and reinjects groundwater continuously. Electron donor (1% to 3% sodium lactate) is being pulsed into the reinjection line approximately once per month. For the passive treatment cell, sodium lactate is being injected into each of three injection wells once per month, with the injection concentration and electron donor mass being

the same for both treatment cells. Once conditions are sufficiently reducing (as evidenced by ferrous iron concentrations greater than 0.5 mg/L, and a decrease in sulfate of at least 10% from baseline), the treatment cells will be bioaugmented using a commercially available bioaugmentation culture (Shaw's SDC-9).

Approximately four months of field activities have been conducted to date for the ER-0513 project. This includes installation of the active recirculation system, well installation for the passive cell, baseline groundwater sampling, tracer testing, and pre-conditioning lactate injection. This white paper describes these activities in detail, and presents results obtained to date.

Active Recirculation System

The wells for the active cell were installed in September and October 2007, along with two of the passive cell wells. The active cell recirculation system itself was constructed, installed, and tested in March and April 2008. The system operates by extracting groundwater from wells AEW-1 and AEW-2 into a 275 gallon surge tank; the surge tank water is reinjected into AIW-1 and AIW-2, which is a distance of 100 ft upgradient from the extraction wells (refer to Figure 1 for well locations). Once the system was functional, it was operated for several days, and water levels were measured in active cell monitoring wells, and in the two existing passive cell monitoring wells, in order to determine the groundwater flow direction in the area of the proposed passive cell wells. Water level data were collected in several wells using transducers, and in other wells by taking water levels using a synoptic water level meter.

This phased approach for treatment cell construction allowed for the opportunity to assess groundwater flow direction in the area of the planned passive cell wells before installing the remaining ten wells. This helped avoid a scenario in which the entire passive treatment cell was installed, only to find out that groundwater did not flow parallel to the treatment cell axis.

Figure 2 shows the measured water levels from both the active cell and the previously installed passive cell wells, under ambient conditions, and with the active cell recirculation system operating (pumped conditions). Note that this figure shows water levels in elevation in feet below mean sea level, implying that groundwater flows in the direction of increasing numbers on the figure. From this figure, the groundwater flow direction was southerly under ambient conditions in both treatment cell areas, and perhaps slightly southwest in the passive cell area under pumped conditions. This was in contrast to the southeastern direction that was assumed based on data available at the time the ESTCP Demonstration Plan was submitted.

Passive Cell Well Installation

In order to account for the more southerly flow direction, placement of some of the active cell wells was adjusted slightly from their original planned locations. These adjustments were made considering interpreted groundwater flow directions as well as accounting for the many underground utilities in the area. The planned and actual locations are presented in Figure 3. The most significant change was moving continuous multi-channel tubing (CMT) well PMW-3 from its planned location southeast of injection well PIW-1 to a location southwest of PIW-1. Also, well PMW-2 was moved from its planned location on the treatment cell axis to a location southwest of PIW-1. Finally, wells PIW-2 and PMW-6 were moved a few feet to the west of their planned locations in order to avoid utilities.

The actual drilling and development of the remaining ten passive cell wells (four monitoring wells, three injection wells, and three CMT wells) was performed from March 24, 2008 through April 11, 2008 After installation of the remaining passive cell wells, a new round of water level measurements was collected under pumped conditions. These are presented in Figure 4, which shows water levels in elevation in feet below mean sea level. From Figure 4, the groundwater flow direction in the area of the passive cell is south to southeast, as opposed to the more southwesterly direction observed when only two wells were installed. Therefore, the placement of injection and monitoring wells in the passive cell should allow for meaningful results to be observed in all monitoring locations.

Baseline Sampling

Baseline sampling for the active cell was completed the week of April 7, 2008. This included sampling the three standard monitoring wells, all ports in the three CMT wells, and the water being produced from the extraction wells (refer to Figure 1 for well locations). Baseline sampling for the passive cell was completed the week of April 21, 2008. This included sampling the six standard monitoring wells, all ports in the three CMT wells, and the three injection wells (refer to Figure 1 for well locations). Both baseline events were conducted with the active cell recirculation system operating. Analytes sampled included VOCs, ethene/ethane/methane, anions (sulfate, chloride, nitrate/nitrite), alkalinity, COD, DNA samples, compound-specific isotope analysis, and iodide tracer (for background measurements).

The ESTCP Demonstration plan called for three sample ports in each CMT well. During installation of both the active and passive cell CMT wells, four sample ports were completed in all CMT wells except PMW-4, which has five sample ports. This was done in order to account for the possibility that some ports would not produce enough water for sampling. During the baseline sampling events, it was determined that the uppermost port in each active cell CMT

well did not produce sufficient water to complete a full set of samples. However, because extra ports were installed in each well, data are available from multiple depths in each CMT well.

Results of baseline sampling are summarized here and are presented in Figures 5 through 9. The VOC contaminant distribution (TCE and c-DCE) is shown in Figures 5 and 6. For the active treatment cell (Figure 5), concentrations were generally around 1,000 to 3,000 μg/L for TCE, with other contaminants present at low levels, but concentrations increased significantly at the southern end of the cell. The highest concentration measured anywhere in the ESTCP demonstration area was 140,000 μg/L at well AMW-6. This is adjacent to a previous chemical oxidation pilot test and was known to be the highest concentration area within the source. The sample collected from the water being extracted from wells AEW-1 and AEW-2 had a TCE concentration of 10,000 μg/L.

For the passive cell (Figure 6), TCE concentrations were around 1,000 μg/L at each end of the treatment cell (wells PMW-1 and PMW-9). However, TCE concentrations were much higher in the center of the passive cell (15,000 μg/L to 63,000 μg/L). Concentrations of other VOC contaminants were low in all passive cell wells.

Vertical profiles of contaminants in CMT wells are shown in Figures 7 and 8. For the active cell (Figure 7), upper zones generally have low levels of contaminants and also produce very little water when purged. TCE concentrations were approximately 600 to 1,800 μg/L in middle to lower zones. For the passive cell (Figure 8), TCE concentrations are generally an order of magnitude higher than the active cell; upper zones had TCE concentrations of 1,000 to 10,000 μg/L, while middle and lower zones had TCE as high as 63,000 μg/L.

Results for other parameters show that the aquifer is generally mildly reducing with low levels of available carbon. Dissolved oxygen is less than 1 mg/L and ferrous iron is generally less than 0.1 mg/L at all locations. Sulfate is very high at this site, with concentrations ranging from approximately 1,600 mg/L to as high as 8,700 mg/L near the area where the chemical oxidation pilot test was conducted. Methane was detected at some wells up to 230 μg/L, while COD ranged from non-detect to 100 mg/L. Overall, the pH is near neutral, and ORP ranges from -150 to +300 mV. The only exception to these general trends is well PMW-9, which has relatively high concentrations of methane of 2.8 mg/L, and somewhat depressed sulfate of 1,100 mg/L. While TCE is lower at this location than others in the passive cell, very low concentrations of reductive daughter products are present, and COD is low as well (16 mg/L). This suggests that while redox conditions may be approaching methanogenesis at location, little dechlorination is occurring.

Baseline DNA sampling showed that indigenous *Dehalococcoides* were only detected at low levels at two monitoring locations – the active extraction wells had 448 + 75 cells/L, and the passive cell well PMW-3 had 110 + 28 cells/L. These cell counts are just above the minimum quantification level for the quantitative polymerase chain reaction (qPCR) analysis, and are four to six orders of magnitude lower than what is typically observed following bioaugmentation. Also, it is important to note that the vinyl chloride reductase (vcrA) gene was not detected in any samples. This is important because the vcrA gene was identified during the DNA studies as the proposed "biomarker" that will be used to distinguish the bioaugmentation culture from any indigenous *Dehalococcoide*s that grow during the demonstration.

The DNA sampling will be continued throughout the pre-conditioning phase in order to monitor increases in *Dehalococcoides* in response to the lactate injections. Also, monitoring for vcrA will be continued to ensure that this functional gene is not detected even if *Dehalococcoides* increases. If these data indicate that the indigenous strain begins to exhibit the vcrA gene, then a more sophisticated analytical approach that involves sequencing the genes will be considered for future samples to distinguish the inoculated *Dehalococcoides* from the indigenous.

Finally, while the full report containing the baseline compound-specific isotope analyses results is not yet available, preliminary results show that the TCE present near the active extraction wells is "heavier" than in other places. This implies that a mechanism which results in fractionation of TCE (i.e. preferential transformation of the TCE molecules with the "lighter" carbon-12 isotope) is or was active in the past in this area. This is consistent with the fact that this area of the site is near the former chemical oxidation pilot test, because chemical oxidation is known to cause fractionation of TCE, similar to what biodegradation causes. Thus, it appears that the effects of the chemical oxidation are still evident in the isotope signatures at this monitoring location. This should not affect data interpretation for the ER-0513 demonstration because future biodegradation will cause further fractionation of TCE, and will also produce daughter products, whose isotope signatures can then be monitored over time.

Active Cell Tracer Test

A tracer test was performed in the active cell in order to determine hydraulic properties and to confirm travel times from the injection to monitoring wells. The ESTCP Demonstration Plan described that either bromide or iodide would be used as the tracer. Since it was determined that the high chloride concentrations at Site 70 (historically as high as 10,000 mg/L) would cause significant interference with a bromide ion specific electrode, iodide was selected as the tracer. Samples were collected for iodide during the baseline sampling to determine the background response to the iodide probe (all samples were approximately 2-4 mg/L).

Approximately 500 gallons of potassium iodide was injected into the active cell on April 10, 2008. The average concentration of iodide in the injected solution was approximately 13,100 mg/L. Samples for iodide tracer were collected once per day from well AMW-2 for approximately four weeks. Periodic CMT monitoring has been performed for the seven weeks since the tracer injection.

Tracer breakthrough curves are shown in Figure 9 for the active cell tracer test. Tracer breakthrough was observed in AMW-2 (18 ft from injection wells) within 2 weeks. Breakthrough was observed at AMW-4 Zone 2 (28 ft) within approximately 2.5 weeks, Zone 1 (33 ft) within 3 weeks, and Zone 3 (24 ft) within 4 weeks. In addition, tracer breakthrough has occurred in AMW-5 Zone 2 and AMW-3 Zone 3 in approximately five weeks, and initial tracer arrival has occurred in the other ports in these CMT wells. These results show that the lower zones are more transmissive, which is also where the higher contaminant concentrations are found in these wells. The long tail on AMW-2 is likely the result of different tracer arrivals in the various lithologic units.

A preliminary analysis of the tracer test data was performed in order to estimate aquifer properties for the purpose of calculating potential ranges of travel times within the passive cell. The model used was developed for an instantaneous point source (Baetlse, 1969). The analytical equation is found in Domenico and Schwartz (1990, p. 650). A hydraulic conductivity of 10 ft/d was assumed as a starting point based on a pumping test performed in the source area at the site several years ago. An effective porosity of 0.20 was assumed based on CDM's experience with this soil type. A longitudinal dispersivity value equivalent to approximately 10% of the scale of the cell was assumed, and the transverse dispersivity was assumed to be 10% of the longitudinal. The hydraulic gradient used was 0.04 based on water level measurements during pumping. The final variable in this model is distance from the axis (or centerline) of transport. Given the two injection wells in the active cell, this analytical model does not perfectly represent the real system, and the distance from the axis has a questionable meaning. Also, solutions using this model will be nonunique as multiple combinations of the conductivity, effective porosity, and distance from the centerline can produce very similar results. Nevertheless, it is believed that this approach is useful to estimate aquifer properties reasonably, especially given the fact that the hydraulic conductivity has previously been measured by a multiple well pumping test at the site.

Using this approach, inverse modeling was performed to estimate a range of hydraulic conductivities based on matching model predictions to measured iodide breakthrough at several of the monitoring locations. The results of this exercise are shown in Figure 10. For the three active cell monitoring locations shown, the hydraulic conductivity ranged from 5 to 10

ft/d. Thus, the tracer test data could be reasonably matched using hydraulic property values consistent with the soil type and previous hydraulic testing at the site. A somewhat more rigorous semi-analytical model is currently being developed to confirm the expected implications of the estimated aquifer properties for the passive cell.

Based on the estimated values of parameters determined by the tracer test as listed above, travel times from passive cell injection wells to passive cell monitoring wells can be estimated. The most significant factor affecting the travel time is the injection event itself. The target injection volume of 1,000 gallons per well is based on achieving a radius of influence of 5 ft. Therefore, it is assumed that the injected substrate will be distributed 5 ft from the injection point at time zero. Given the range of hydraulic conductivities that were estimated based on the tracer test, along with the measured groundwater elevations presented in Figure 4, groundwater velocity in the passive cell is approximately 4-8 ft/month, or 45-90 ft/yr. This is well within the range of ambient groundwater velocity at other sites where bioremediation and bioaugmentation have been successful, and is in fact two to four times higher than what was originally assumed in the ER-0513 ESTCP Demonstration Plan.

The transport during injection combined with advection under ambient conditions results in travel times from injection wells PIW-1 and PIW-3 to their corresponding monitoring wells ranging from one to three months, assuming conductivity is 10 ft/d. Even if the low estimate of 5 ft/d for conductivity is assumed, travel times from PIW-1 and PIW-3 range from two to five months. Well PIW-2 has a monitoring well located 8 ft away (PMW-6), and another monitoring well located 29 ft away (PMW-7). Depending on the local flow direction in this area, travel times to PMW-6 could be less than one month, while travel times to PMW-7 could be three to seven months.

Pre-conditioning lactate injections and sampling

The initial lactate injection in the active cell was performed on April 23, 2008. Approximately 3,000 gallons was injected at a weight concentration of 1% (i.e. 10,000 mg/L). The initial passive cell lactate injection has not yet been performed, pending resolution of the injection approach with the Remedial Project Manager, the onsite Seal Beach environmental coordinator, and the ESTCP project team.

A monthly sampling event (pre-conditioning monthly event #1) in the active cell wells was performed the week of May 12, 2008. This included the three standard monitoring wells, extraction wells, and one port only from each of the CMT wells. Preliminary results from this sampling round suggest that effects of recirculation are beginning to be observed in the nearest monitoring well AMW-2, in that contaminant profiles and geochemistry are becoming more like

that of the water extracted from AEW-1 and AEW-2. Thus far, effects of the first lactate injection are not evident in this well.

Recommendations

The data collected during field construction, baseline sampling, and tracer testing indicate that meaningful results will be obtained during the 12-month duration of the bioaugmentation portion of the ER-0513 project, allowing for the project objectives to be met Most importantly, the aquifer hydraulics as determined from the tracer test are such that effects of lactate injections and bioaugmentation will be observed at most monitoring wells within three to six months (if not earlier). In addition, VOC concentrations are sufficiently high to support growth of the injected bioaugmentation culture, and the mildly reducing redox conditions can be driven to methanogenesis through the pre-conditioning lactate additions. Finally, the DNA studies and DNA sampling conducted to date suggest that the vcrA functional gene can be used to track the added bioaugmentation culture as planned.

Based on all of these factors, it is recommended that the ER-0513 project be continued as outlined in the ESTCP Demonstration Plan. Pre-conditioning lactate injections will be performed for an additional two months, and a final pre-conditioning sampling event will be conducted to ensure that the vcrA gene has not proliferated prior to bioaugmentation. Also, iodide tracer will be injected into one of the passive cell injection wells in order to confirm the predicted travel times from injection to monitoring wells. The sampling frequency following bioaugmentation is currently planned for monthly, but a recommendation to modify that might be made depending on the sampling results for the pre-conditioning phase. Based on the current schedule of activities, it is anticipated that bioaugmentation will be performed in late July to early August 2008.

Very truly yours,

Joey Trotsky
NAVFAC ESC

Kent S. Sorenson, Jr., Ph.D., P.E.
Vice President
CDM

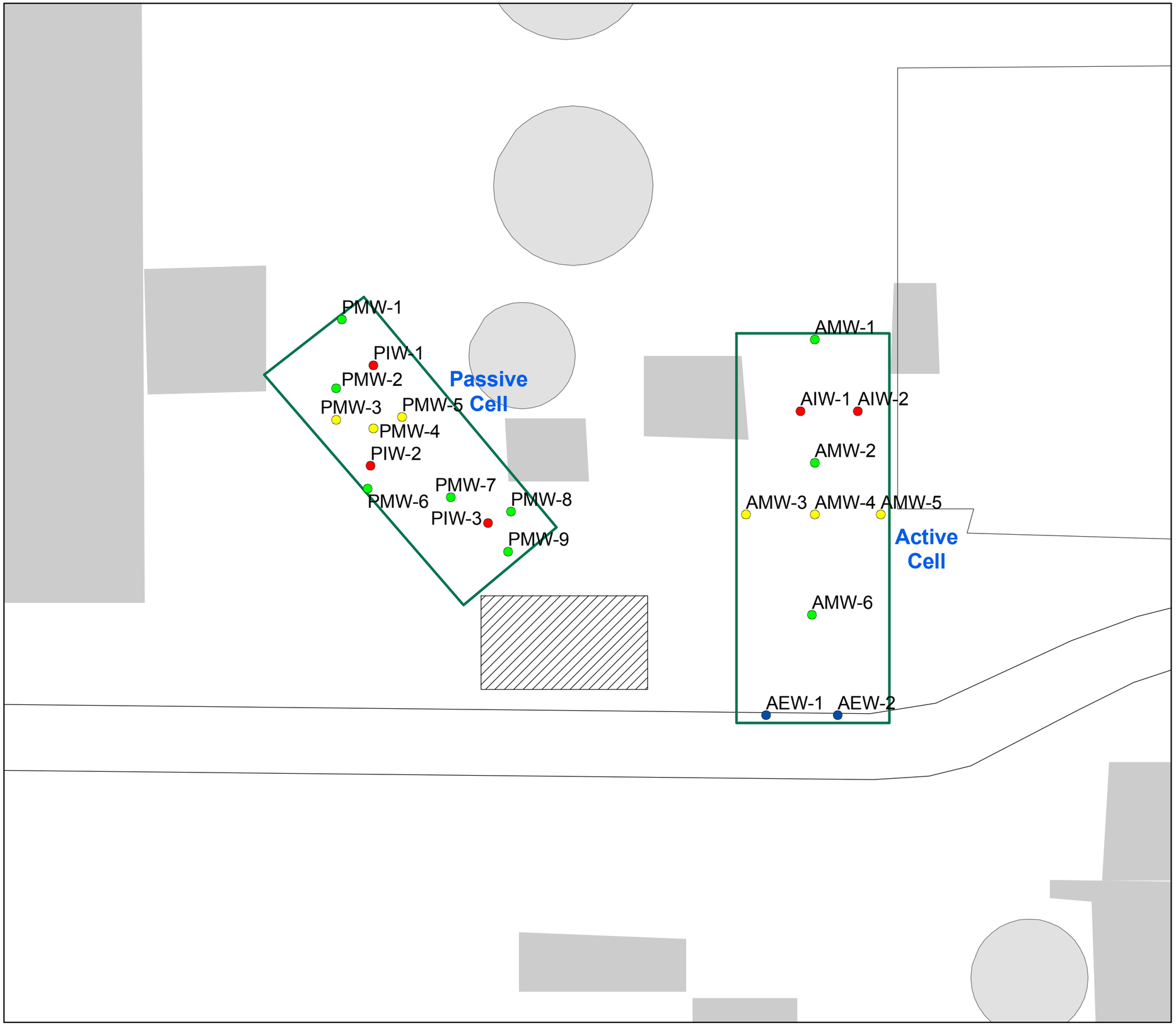
cc: Ryan A. Wymore, P.E., CDM

Attachment

Figure 1 – Site map
Figure 2 – Active Recirculation Water Levels
Figure 3 – Passive Cell Well Installation
Figure 4 – Actual Water Levels
Figure 5 – Active Cell VOC Concentrations
Figure 6 – Passive Cell VOC Concentrations
Figure 7 – Active Cell Vertical Profiles
Figure 8 – Passive Cell Vertical Profiles
Figure 9 – Active Cell Tracer Breakthrough Curves
Figure 10 – Preliminary Tracer Test Data Analysis

Figure 1 - Site Map

Project ER-0513
Naval Weapons Station Seal Beach
Site 70
Seal Beach, California



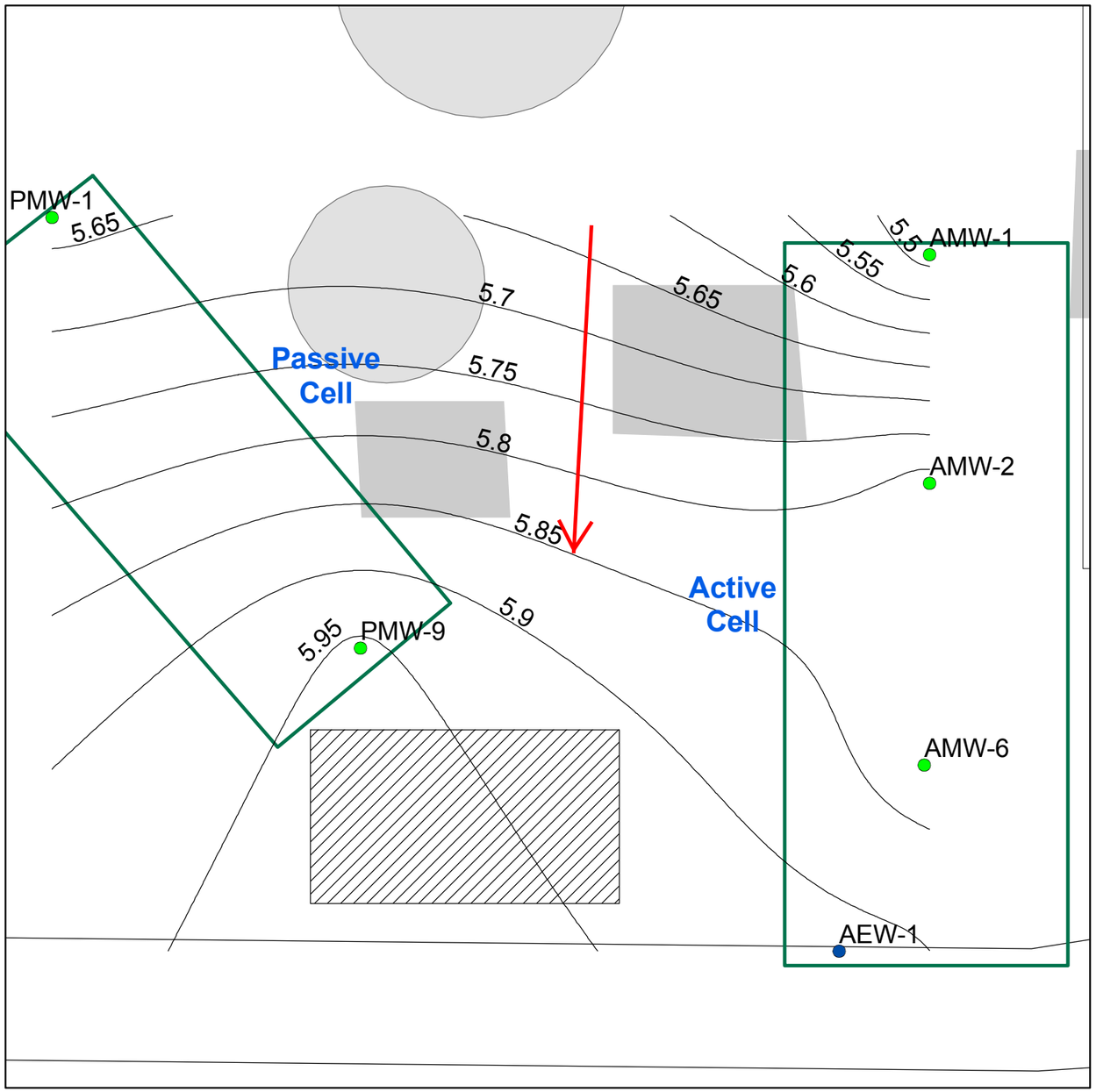
Well Types

- Monitoring Well
- Injection Well
- Extraction Well
- CMT Well

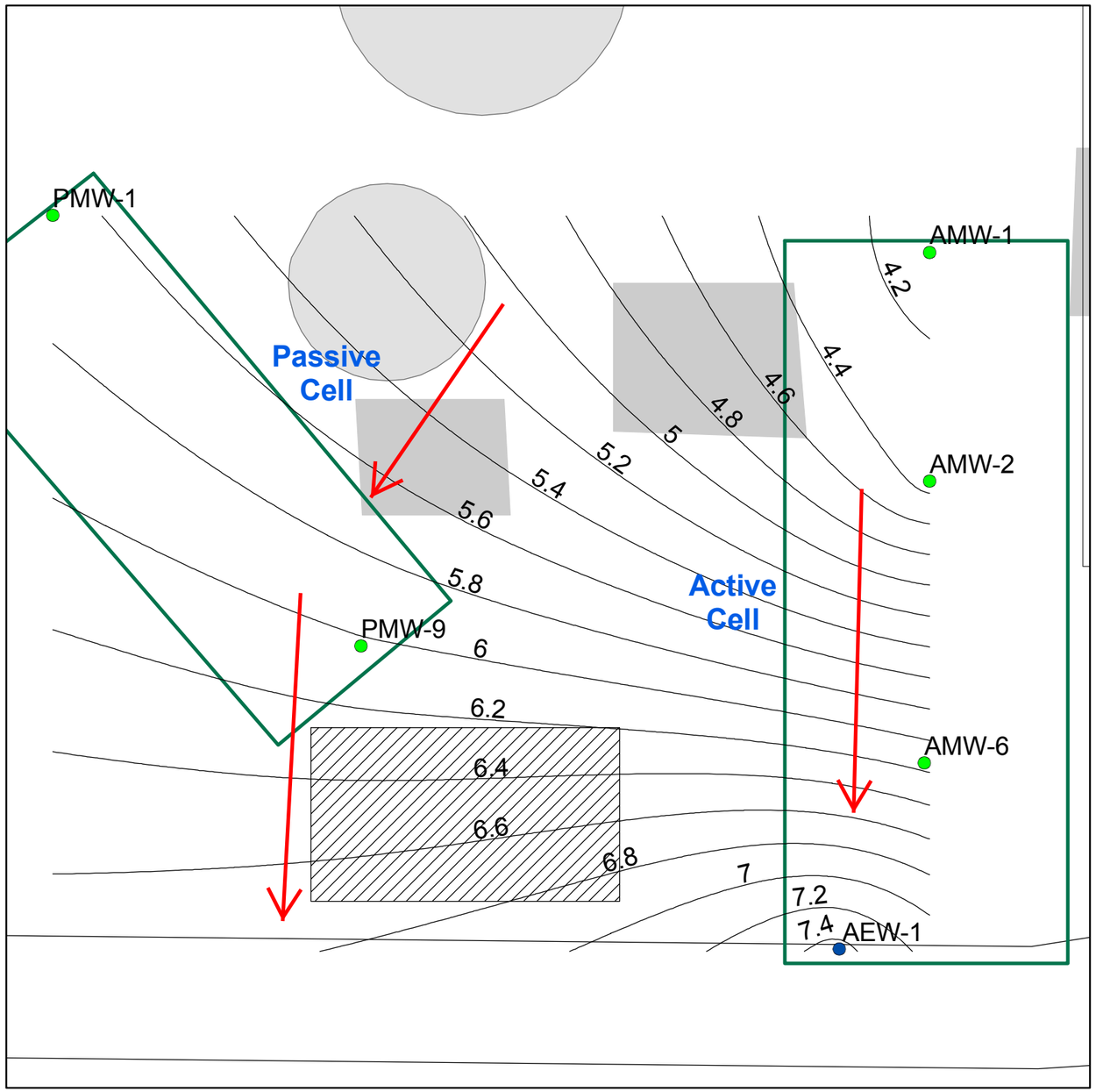
0 12.5 25 50 75 100 Feet

N
W E
S

CDM



Ambient Conditions



Pumping Conditions

Figure 2 - Active Recirculation Water Levels (feet below mean sea level)

Well Types

- Monitoring Well
- Extraction Well

0 5 10 20 30 40 Feet

N W E S

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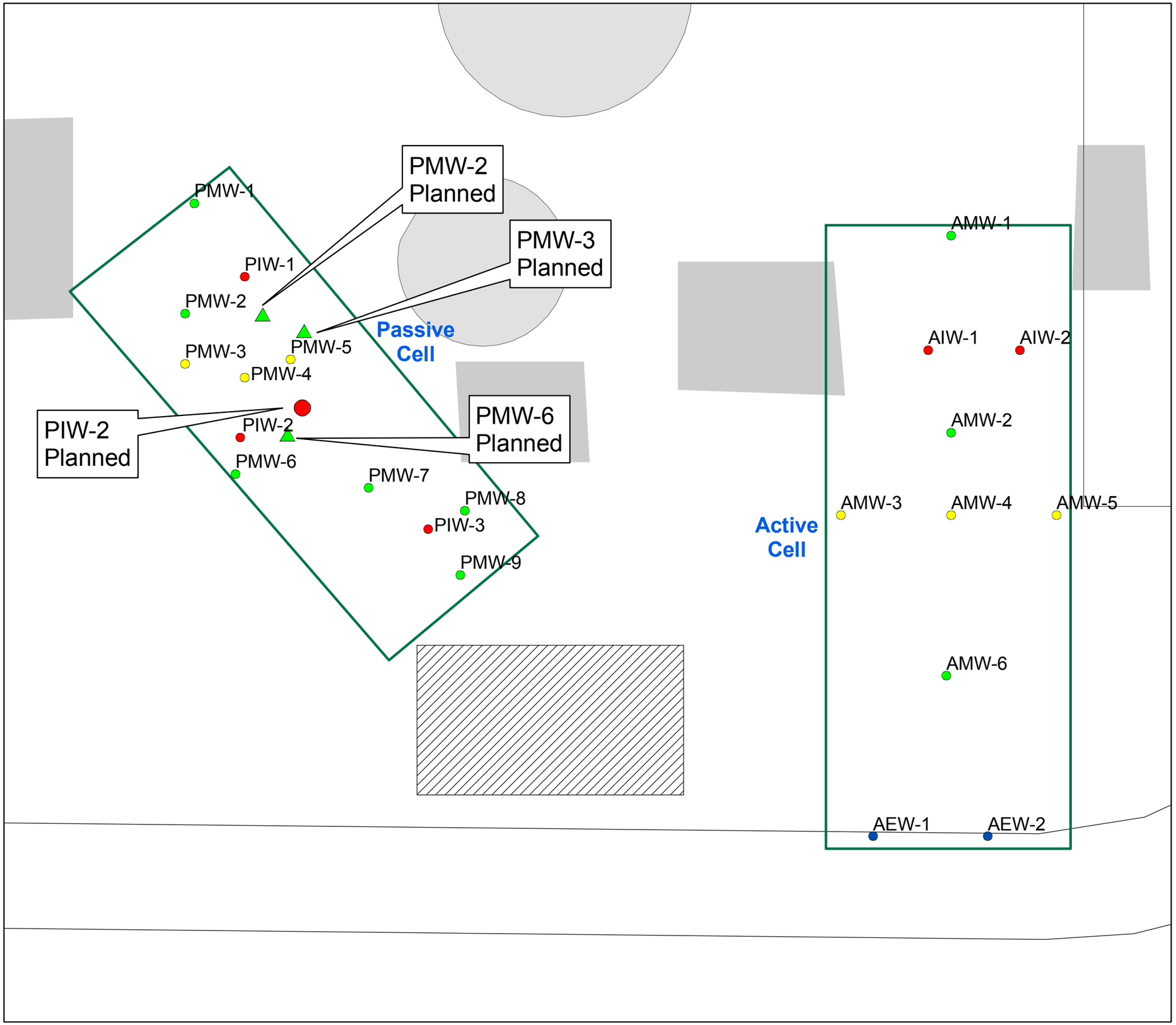
Naval Weapons Station Seal Beach
Site 70
Seal Beach, California

CDM

Figure 3 - Passive Cell Well Installation

Project ER-0513
Naval Weapons Station Seal Beach
Site 70
Seal Beach, California



Planned Locations of Passive Wells

- Monitoring Well
- Injection Well

Well Types

- Monitoring Well
- Injection Well
- Extraction Well
- CMT Well

0 5 10 20 30 40
Feet

N
W E
S

CDM

Figure 4 - Actual Water Levels (feet below mean sea level)

Project ER-0513
Naval Weapons Station Seal Beach
Site 70
Seal Beach, California

PMW-1
PIW-1
PMW-2
PMW-3
PMW-4
PMW-5
PIW-2
PMW-6
PMW-7
PMW-8
PIW-3
PMW-9
Passive Cell
Active Cell
AMW-1
AIW-1
AIW-2
AMW-2
AMW-3
AMW-4
AMW-5
AMW-6
AEW-1
AEW-2
4.9
5
5.1
5.2
5.3
5.4
5.5
5.6
5.7
5.8
5.9
6
6.1
6.2
6.3
6.4
6.5
6.6
6.7
6.8
6.9
7
7.1
7.2
7.3
7.4
7.5
7.6
7.7
7.8
7.9
8

Well Types

- Monitoring Well
- Injection Well
- Extraction Well
- CMT Well

0 5 10 20 30 40
Feet

N
W E
S

CDM

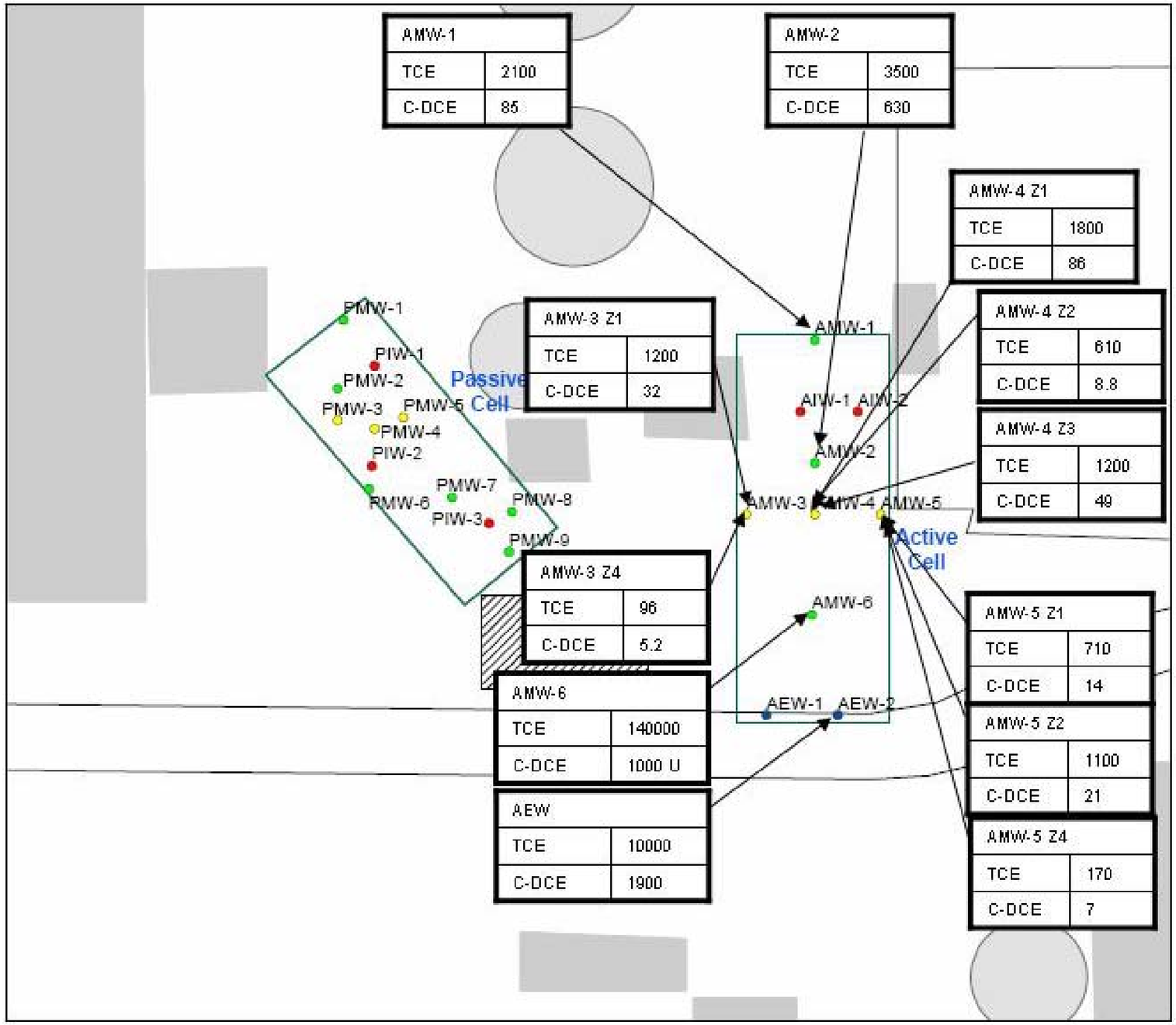


Figure 5 - Active Cell VOC Concentrations (ppb)

Project ER-0513
Naval Weapons Station Seal Beach
Site 70
Seal Beach, California

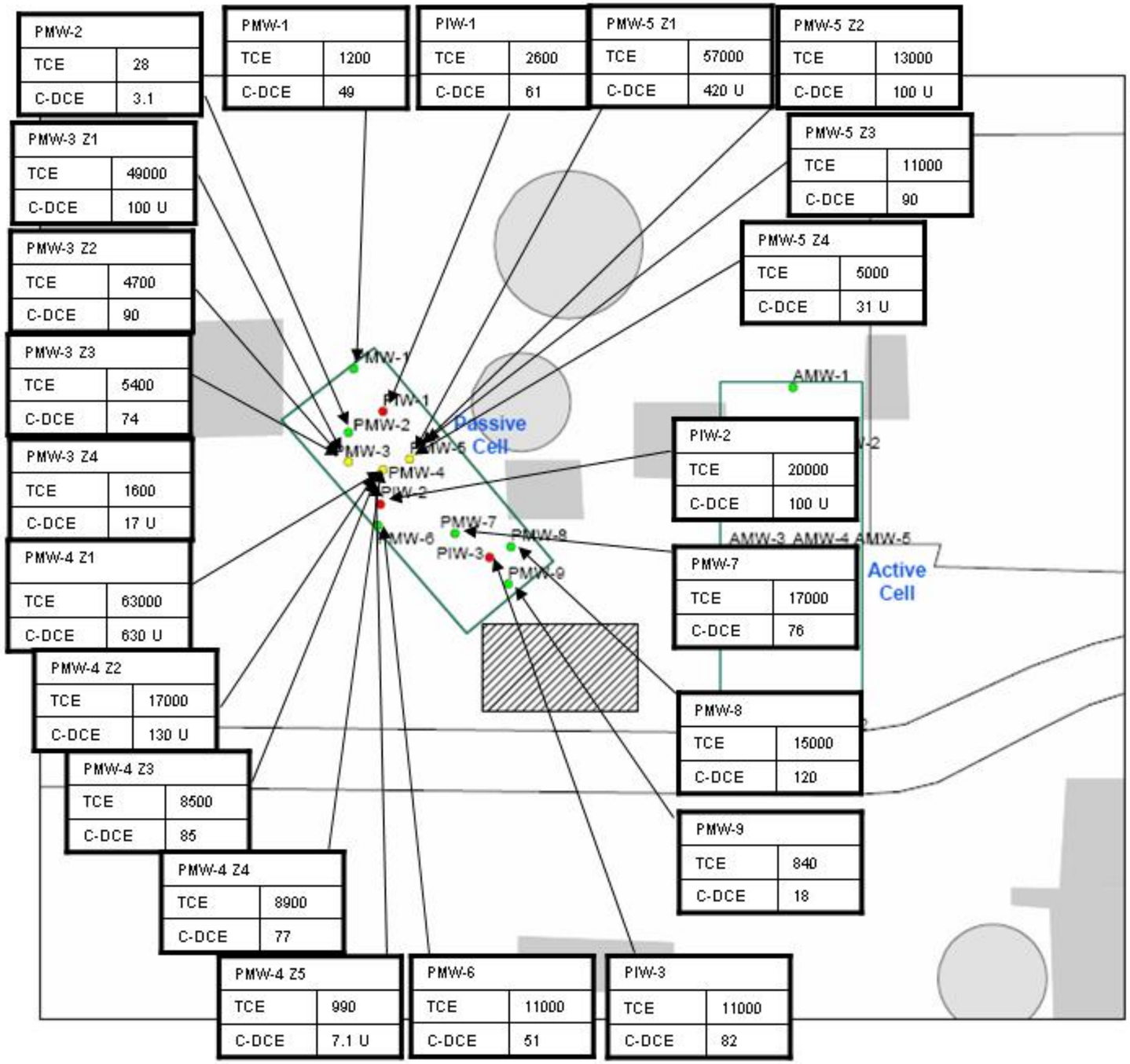


Figure 6 - Passive Cell VOC Concentrations (ppb)

Project ER-0513
Naval Weapons Station Seal Beach
Site 70
Seal Beach, California

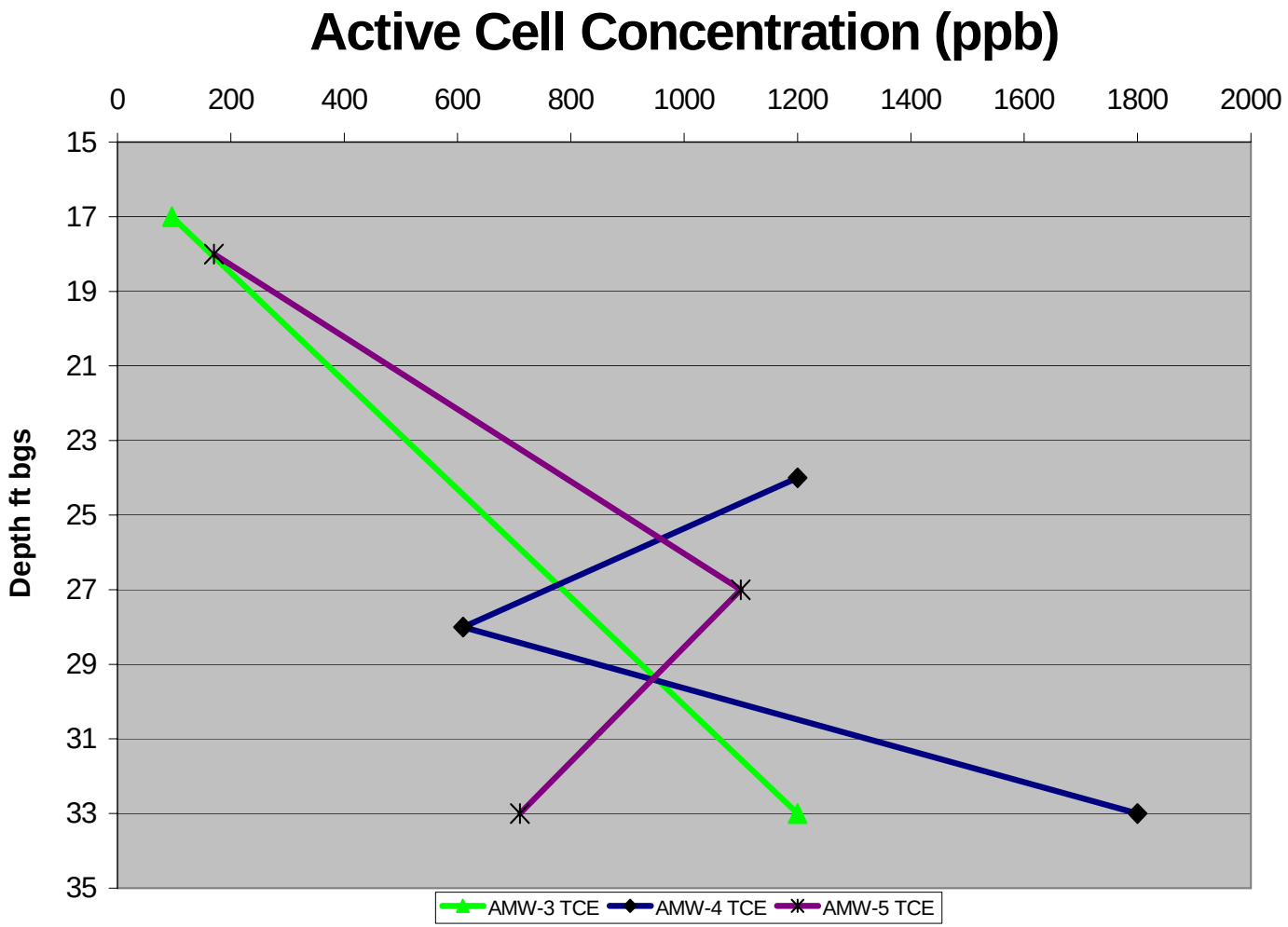


Figure 7 – Active Cell Vertical Profiles

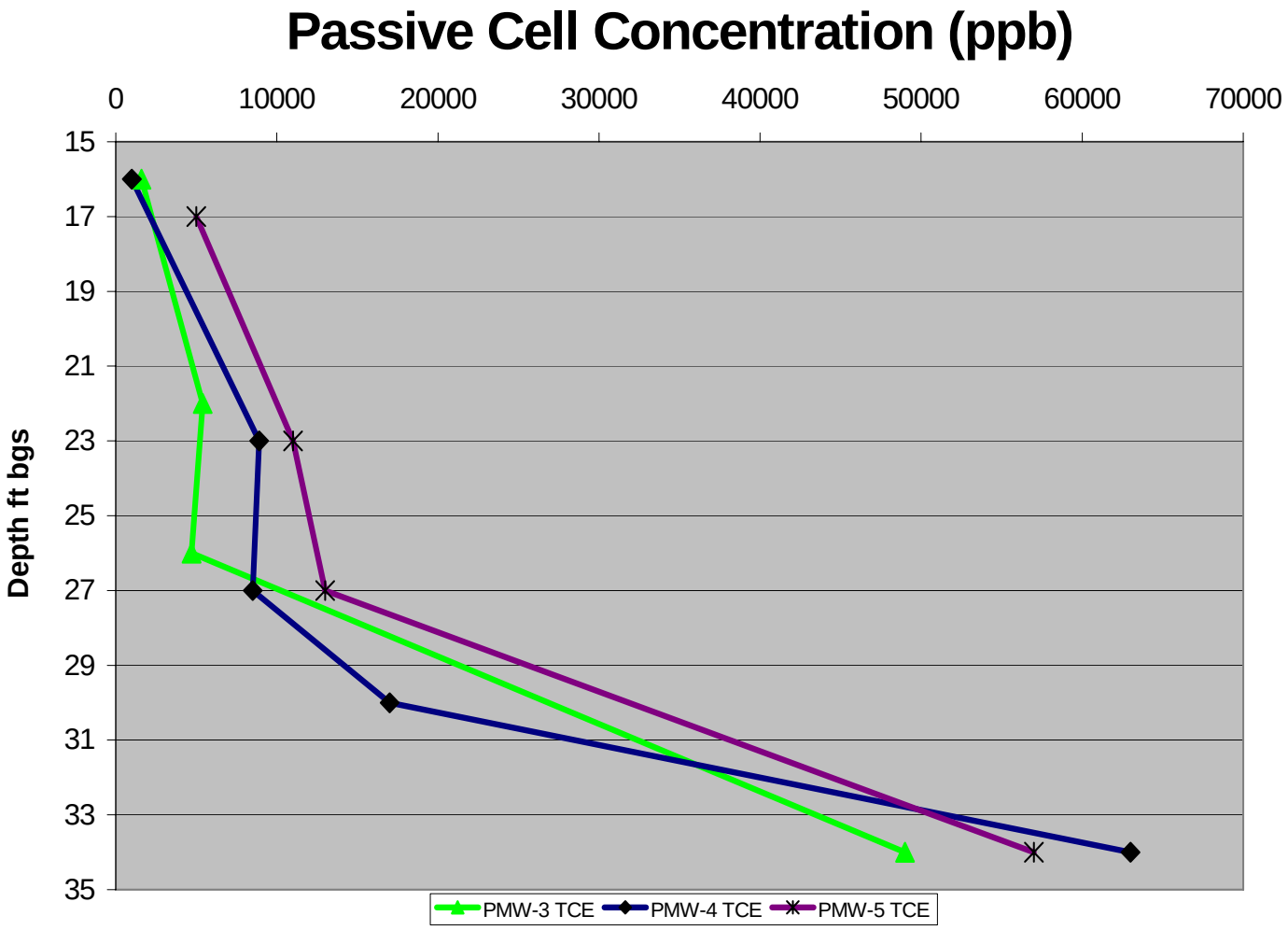


Figure 8 – Passive Cell Vertical Profiles

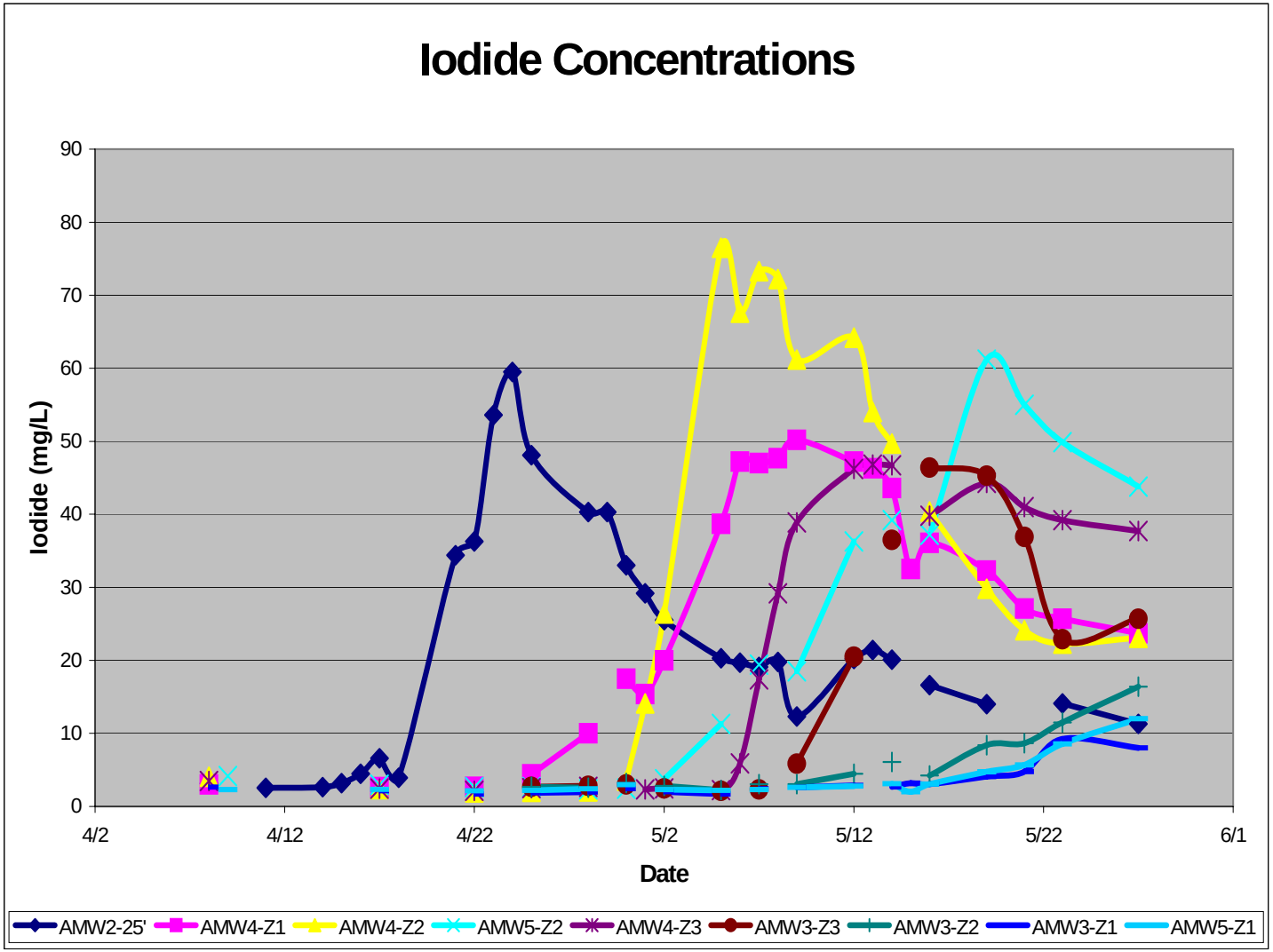


Figure 9 – Active Cell Tracer Breakthrough Curves

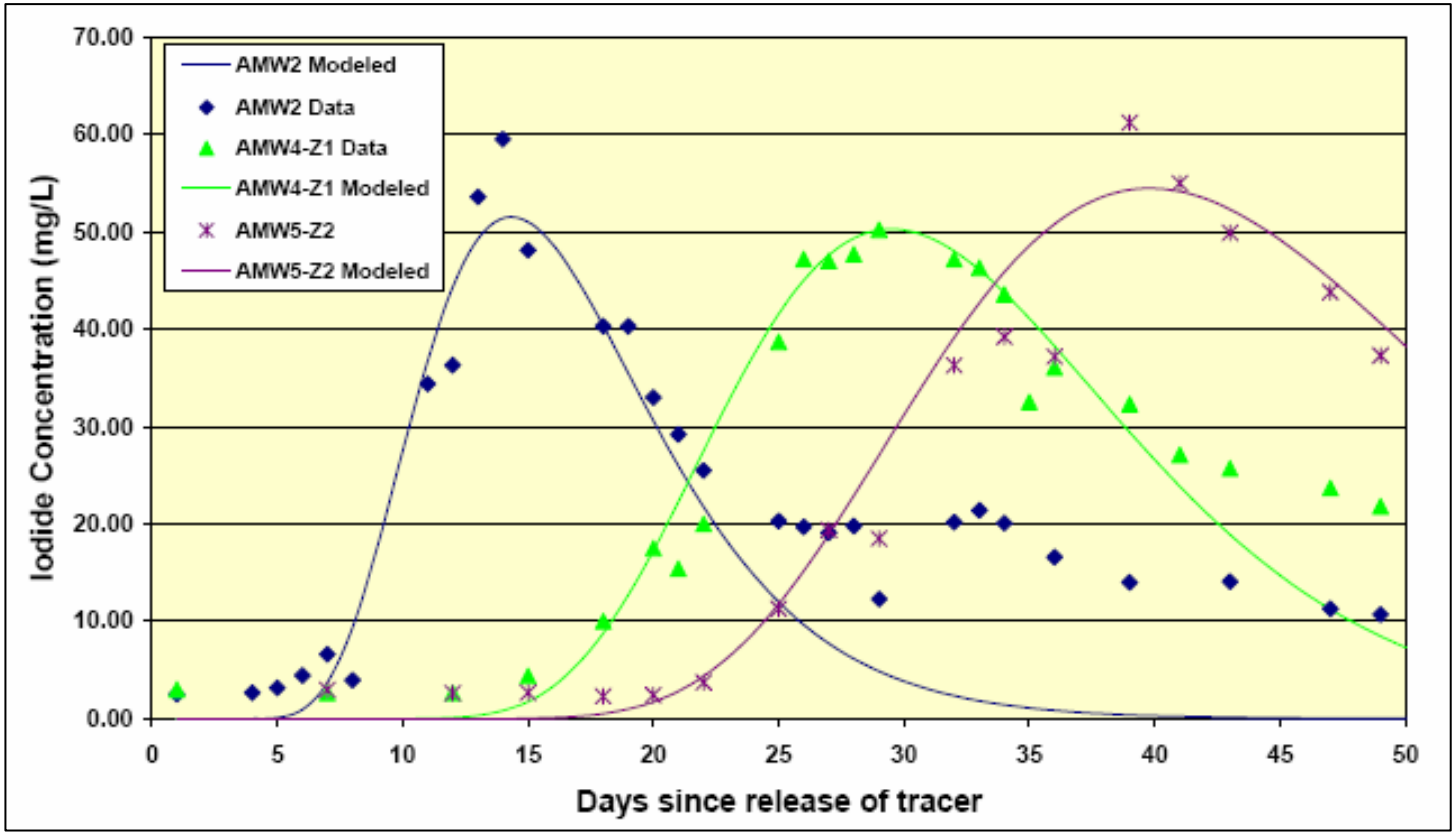


Figure 10 - Preliminary Tracer Test Data Analysis
K = 7.5-10 ft/d (pumping test), n = 0.20, dh/dL = 0.04

December 29, 2008

Ms. Andrea Leeson, Ph.D.
ESTCP Program Office
901 North Stuart Street, Suite 303
Arlington, VA 22203

Subject: Pre-Conditioning Results for ER-0513

This White Paper presents results of the "pre-conditioning" phase for Environmental Security Technology Certification Program (ESTCP) project ER-0513, with the intent of documenting that conditions are appropriate for bioaugmentation, as directed by the ESTCP program office in an email dated August 5, 2008. This project is being conducted at Naval Weapons Station Seal Beach, Site 70. The purpose of this demonstration is to compare the low-cost, passive approach for bioaugmentation to the more common recirculation approaches for full-scale TCE source area application.

Project field work began in February 2008 with construction of the active recirculation treatment cell. This was followed by the initiation of the "pre-conditioning" phase during which electron donor was added to both the active and passive treatment cells in order to establish appropriate reducing conditions in the aquifer prior to bioaugmentation. The active recirculation cell extracts and reinjects groundwater continuously, and electron donor (1% to 3% sodium lactate) is being pulsed into the reinjection line periodically. To date, three active cell injections have been performed from late April to mid-October 2008. For the passive treatment cell, sodium lactate was injected into each of three injection wells once per month between August and October 2008, with the injection concentration and electron donor mass being the same for both treatment cells. Groundwater conditions were monitored following each injection event during the pre-conditioning phase, in order to determine when sufficiently reducing conditions were achieved. In the June 9, 2008 white paper submitted to ESTCP, these conditions were defined as ferrous iron concentrations greater than 0.5 mg/L and a decrease in sulfate of at least 10% from baseline. Once conditions are shown to be sufficiently reducing, the treatment cells will be bioaugmented using a commercially available bioaugmentation culture (Shaw's SDC-9).

Pre-conditioning lactate injections and sampling

The initial lactate injection in the active cell was performed on April 23, 2008. Two additional injections were conducted on July 17, 2008 and October 17, 2008. Approximately 3,000 gallons

were injected at a weight concentration of approximately 1% (i.e., 10,000 mg/L) as lactate. The initial passive injection was performed on August 6, 2008. Two additional injections were conducted on September 8, 2008 and October 21, 2008. Approximately 3,200 gallons (1,066 gallons per well) were injected at a weight concentration of 1% during each event.

Baseline sampling as completed for the active cell the week of April 7, 2008 and for the passive cell the week of April 21, 2008. Well details are shown in Table 1, and well locations are shown in Figure 1. The baseline sampling included sampling the three standard monitoring wells, all ports below the water table in the three CMT wells, and the water being produced from the extraction wells (refer to Figure 1 for well locations). Sampling was also conducted in September, October, and November 2008 to monitor groundwater conditions during pre-conditioning. The September and October events included sampling the same wells as the baseline event, except only the deepest zones (Zone 1) in the CMT wells were sampled. The November 2008 event was the final sampling event during pre-conditioning and included all the wells (and zones) included in the baseline event.

All active cell sampling events were conducted with the active cell recirculation system operating. Analytes sampled during all events included volatile organic compounds (VOCs), ethene/ethane/methane, anions (sulfate, chloride, and nitrate/nitrite), alkalinity, chemical oxygen demand (COD), and DNA samples. During the baseline and final sampling events, stable carbon isotope analysis was also performed.

Active Recirculation Cell Results

Electron Donor

Electron donor results as chemical oxygen demand (COD) are shown in Table 2. In general, COD concentrations did not increase significantly during pre-conditioning activities in the active cell. Given that donor injections were conducted approximately 6-8 weeks apart with continuous recirculation being conducted throughout this time, it is believed that the lactate may have been diluted and "washed out" from the monitoring wells. Because of this, smaller, more frequent injections will be performed during the bioaugmentation phase. Despite this observation in the monitoring wells, the redox data and VOC results clearly show that the lactate injections have had positive impacts in the active cell nearer the injection wells, in terms of driving conditions to be appropriate for bioaugmentation (see below).

Redox Parameters

Redox parameter results are also shown in Table 2. Ferrous iron was not detected at any wells during baseline sampling except for in the deepest zone (Z1) of AMW-4 and AMW-5.

However, ferrous iron concentrations increased by November 2008 to greater than 3 mg/L at AMW-2, which is the closest downgradient well to the injection wells. Also, ferrous iron concentrations increased to above 0.5 mg/L at all three of the CMT wells further downgradient.

Sulfate concentrations decreased over 65% from 7,400 mg/L to 2,600 mg/L at AMW-2. Sulfate concentrations also decreased more than 20% from baseline conditions at AMW-3 Z1 (24%), AMW-4 Z2 (52%), AMW-4 Z3 (53%) and at AMW-5 Z2 (46%), and upgradient well AMW-1 (38%). Sulfate concentrations did increase at the deepest zone of AMW-5 Z1 from 3,600 mg/L to 4,900 mg/L. Sulfate concentrations remained relatively stable at AMW-4 Z1 and AMW-6.

Other electron acceptors nitrate and methane were also analyzed. Nitrate was not detected at any well during the final pre-conditioning sampling event. Methane concentrations were also below 50 µg/L at all wells except the extraction points.

Overall, these results show that redox conditions in the active cell at wells near the injection points are iron- to sulfate-reducing, which is appropriate for bioaugmentation. While the entire active cell is not yet at the appropriate redox conditions, it is only a requirement for the portion of the aquifer where the culture will be injected to have the appropriate redox conditions. The remainder of the active cell will achieve the appropriate conditions as the bioaugmentation phase progresses.

Contaminants and Degradation Products

Results of baseline (April 2008) and final pre-conditioning (November 2008) sampling events are summarized and are presented in Table 3 for VOC compounds. Trichloroethene (TCE) concentrations were generally around 1,000 to 3,000 µg/L during baseline sampling, with the exception of the extraction wells (10,000 µg/L) and well AMW-6 (140,000 µg/L); other contaminants were present at low levels. The November 2008 final pre-conditioning VOC contaminant distribution is shown in Figure 2 for tetrachloroethene (PCE), TCE, and cis-1,2-dichloroethene (c-DCE). In general, TCE concentrations were higher than baseline in all wells except AMW-6 (decrease from 140,000 µg/L to 120,000 µg/L) and AMW-2 (3,500 µg/L to 1,300 µg/L). This is due to the fact that the recirculation system is extracting groundwater with higher TCE concentrations and reinjecting it upgradient. The highest TCE concentration measured anywhere in the ESTCP demonstration area remained at well AMW-6 (120,000 µg/L). Vinyl chloride (VC) was not detected at any wells except for AMW-2 (35 µg/L). The sample collected from the water being extracted from wells AEW-1 and AEW-2 had a TCE

concentration of 35,000 µg/L, higher than the baseline concentration of 10,000 µg/L. The c-DCE concentration remained stable at 1,700 µg/L.

The VOCs present at AMW-2 during the November 2008 round are significant in that they show partial dechlorination is already occurring. The results of this event show that significant c-DCE is present at this location, as well as low levels of VC. This is consistent with the other data from this well, which show that conditions are sulfate-reducing.

Vertical profiles of primary contaminant TCE in active cell CMT wells are shown in Figure 3 for April 2008 and November 2008 sampling events. Under baseline conditions, the vertical profile for all 3 CMT wells showed lower overall TCE concentrations and an increase in TCE concentrations with depth. In November 2008, upper zones generally had similar TCE concentrations as deeper zones, probably due to the recirculation. TCE concentrations ranged from 520 to 10,000 µg/L in the three active zone CMT wells.

DNA Results

DNA analysis results using quantitative polymerase chain reaction (qPCR) are provided in Table 4. These results show that indigenous *Dehalococcoides* were only detected at low levels at two monitoring locations (AMW-2 and AMW-4 Z1) and the extraction wells – the monitoring wells had up to $3.4x10^3 \pm 810$ cells/L and the extraction wells had $1.1x10^4 \pm 5300$ cells/L. Although these cell counts are higher than the baseline concentrations, some increase in *Dehalococcoides* was expected after lactate injection. However, it is important to note that the vinyl chloride reductase (*vcrA*) gene was not detected in any samples. This is key because the *vcrA* gene was identified during the DNA studies as the proposed "biomarker" that will be used to distinguish the bioaugmentation culture from any indigenous Dehalococcoides that grow during the demonstration.

Active Cell Summary

Active cell results indicate that appropriate conditions have been achieved for successful bioaugmentation, particularly in wells near the reinjection locations. Ferrous iron increases were observed to above 0.5 mg/L in all wells except AMW-6 and upgradient well AMW-1. Also, sulfate concentrations decreased more than 10% except in AMW-6 and the extraction wells. While COD concentrations did not increase above 60 mg/L in any active cell well, the significantly increased c-DCE concentration at AMW-2 and other wells indicates that partial dechlorination is occurring near the injection wells.

Passive Cell Results

Electron Donor

Electron donor (COD) results are shown from the baseline and final pre-conditioning events in Table 2. Baseline conditions showed that COD was at or below 100 mg/L throughout the passive cell. In November 2008, COD concentrations increased to above 1,000 mg/L in wells PMW-6, PMW-7, PIW-2, and PIW-3 and increased to near or above 100 mg/L in wells PMW-2, PMW-3 Z1, and PIW-1. COD only decreased slightly in wells PMW-1, PMW-9, and in the upper zones of all three CMT wells. These results indicate that donor has increased significantly in the areas surrounding the injection wells throughout the passive cell.

Redox Parameters

Electron acceptor results are also shown in Table 2. Ferrous iron was not detected at any wells during baseline sampling except for in the upper zone of PMW-5. The November 2008 results show that ferrous iron concentrations increased to above 0.5 mg/L at PMW-2, PMW-6, and PMW-8, which are the closest downgradient wells to injection wells PIW-1, PIW-2, and PIW-3, respectively. Also, ferrous iron concentrations increased to above 0.5 mg/L for at least one zone of all three CMT wells further downgradient.

Baseline sulfate concentrations were high in the passive cell, ranging from 1,100 mg/L in PMW-9 to 5,800 mg/L in PMW-5 Z3. Following the lactate injections, sulfate concentrations decreased from baseline conditions between 35% and 99% in the three injection wells. Sulfate concentrations also decreased more than 10% from baseline conditions in PMW-7 (13%) and PMW-8 (21%), while remaining relatively stable in the three CMT wells and PMW-6. Sulfate concentrations did increase over 100% in wells PMW-2 and PMW-9. Also, upgradient well PMW-1 increased in sulfate concentration from baseline by 24%.

Other electron acceptors nitrate and methane were also analyzed. Nitrate was not detected in any well during the final pre-conditioning sampling event except upgradient well PMW-1 (0.72 mg/L). Methane concentrations were above 0.1 mg/L in all monitoring wells except AMW-1 and AMW-2.

Overall, these redox conditions show that most of the passive cell wells are iron- to sulfate-reducing, and possibly even methanogenic based on methane concentrations of greater than 200 µg/L at some wells. These results indicate that conditions are appropriate for bioaugmentation in the passive cell.

Contaminants and Degradation Products

Passive sampling VOC results are summarized and are presented in Table 3 for the baseline and final pre-conditioning sampling events. The VOC contaminant distribution is shown in Figure 2 for PCE, TCE, and c-DCE. During the baseline event, TCE concentrations were approximately 1,000 µg/L at each end of the treatment cell (wells PMW-1 and PMW-9). However, TCE concentrations were much higher in the center of the passive cell (15,000 µg/L to 63,000 µg/L). Concentrations of other VOC contaminants were low in all passive cell wells.

The results indicate that TCE concentrations were similar to baseline in all wells except the injection wells, which all decreased two orders of magnitude, and PMW-2, which increased from 28 µg/L to 1,600 µg/L. The highest concentration of TCE was still in the center of the cell, with concentrations in the lowest zone of the three CMT wells, ranging from 37,000 µg/L in PMW-5 to 60,000 µg/L in PMW-3. As opposed to the active recirculation cell, concentrations of degradation product c-DCE did not increase significantly from baseline conditions. No vinyl chloride was detected in the passive cell.

Vertical profiles of TCE in passive cell CMT wells are shown in Figure 4 for April 2008 and November 2008 sampling events. For the passive cell, TCE concentrations are generally an order of magnitude higher in the lower zone (Z1) than the upper zone (Z3-Z4) in all wells; upper zones had TCE concentrations of 4,800 to 9,100 µg/L, while lower zones had TCE as high as 63,000 µg/L. This profile is similar to the profile observed during baseline conditions.

DNA Results

DNA results (Table 4) show that indigenous *Dehalococcoides* were not detected in any wells in the passive cell during the November 2008 sampling event, including functional gene *vcrA*. This is important because the *vcrA* gene was identified during the DNA studies as the proposed "biomarker" that will be used to distinguish the bioaugmentation culture from any indigenous *Dehalococcoides* that grow during the demonstration.

Passive Cell Summary

Passive cell results indicate that conditions are becoming more reducing, with the most positive results observed near the injection wells. In these wells, ferrous iron increased to above 0.5 mg/L and sulfate decreased more than 10% except in PMW-2 and PMW-6. COD increased significantly at wells near the injection points also, and significant COD still remains at two of the three injection wells. This indicates that sufficient electron donor is being supplied for bioaugmentation.

Recommendations

The data collected during the pre-conditioning phase indicate conditions at and near the injection wells are appropriate for bioaugmentation . Electron acceptor results in both cells show that ferrous iron concentrations have generally increased to above 0.5 mg/L, with higher concentrations observed closer to the injection wells. Additionally, sulfate concentrations generally decreased over 10% near the injection wells in both cells from baseline conditions, indicating that the lactate additions are making the subsurface more reducing. The active recirculation cell results indicate that increased dechlorination is occurring following the lactate injections, but dechlorination beyond c-DCE has not generally been observed.

Most importantly, the DNA results indicate that low populations of *Dehalococcoides* are present in the treatment cells as expected, but that the *vcrA* gene has not been detected anywhere. This indicates that the *vcrA* functional gene can be used to track the added bioaugmentation culture as planned.

Based on all of these factors, it is recommended that bioaugmentation be performed in early January in both the active and passive treatment cells using the commercially available culture SDC-9. Please provide us with confirmation that we can move forward with bioaugmentation as planned.

Very truly yours,

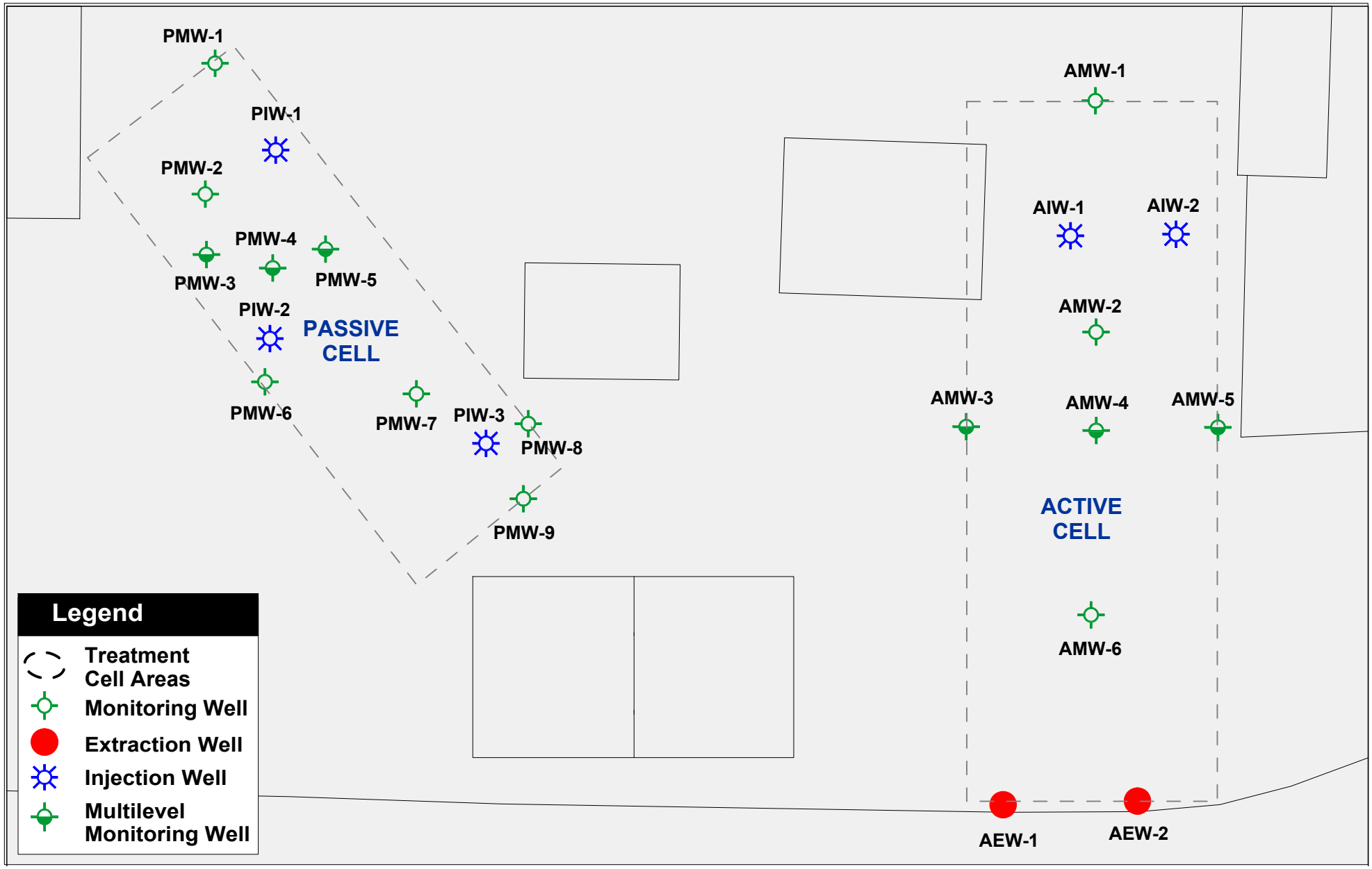
Joey Trotsky
NAVFAC ESC

Kent S. Sorenson, Jr., Ph.D., P.E.
Vice President
Camp Dresser & McKee Inc.

cc: Ryan A. Wymore, P.E., CDM

Attachments

Figures



N
W E
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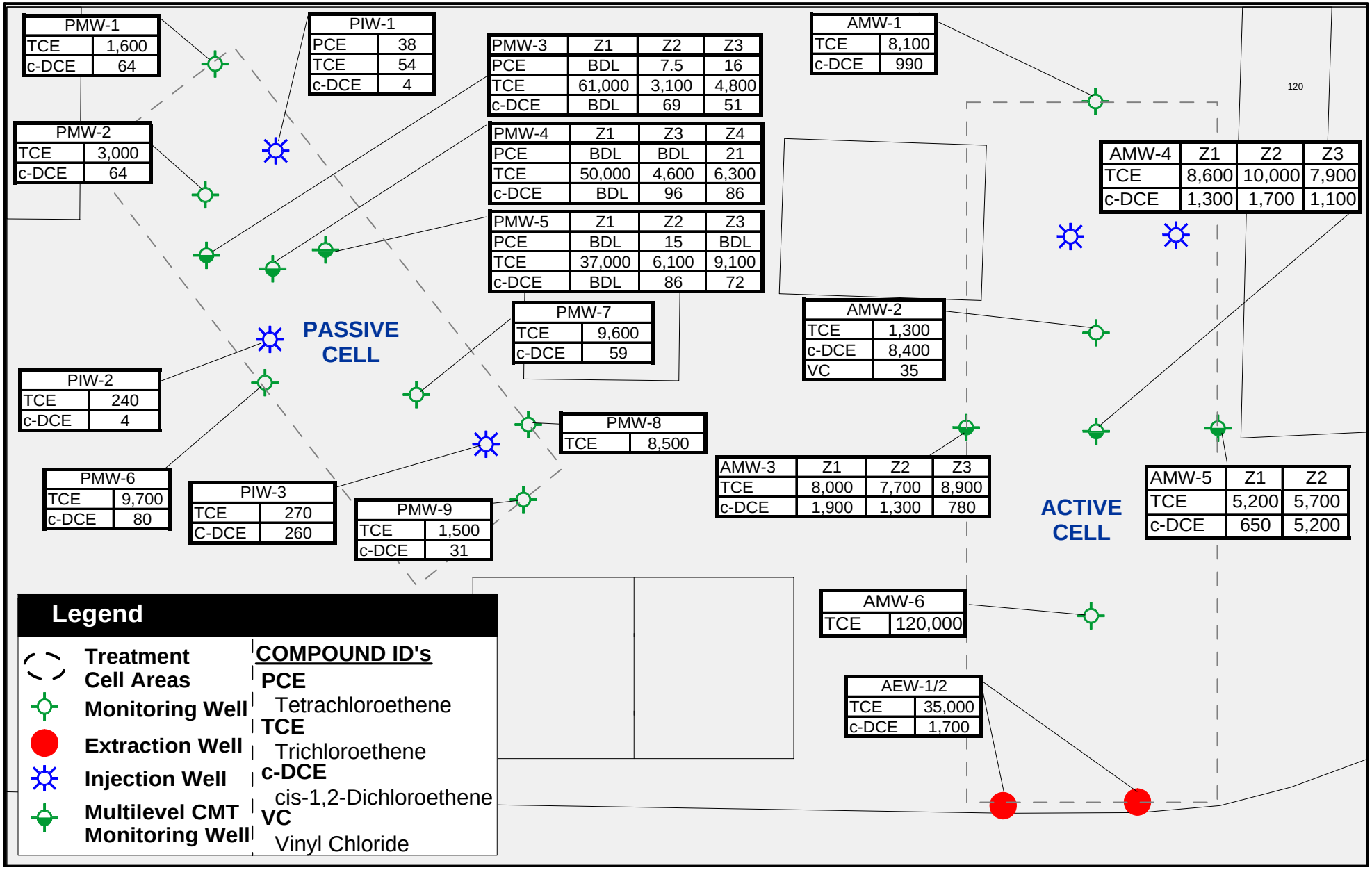
Scale in Feet

12.5 Feet 0 25 Feet

CDM

Figure 1
Site Map

Project ER-0513
Naval Weapons Station Seal Beach
Site 70
Seal Beach, California



*All Concentrations in ug/L
Only detected compounds are displayed.
BDL - Below detection limit

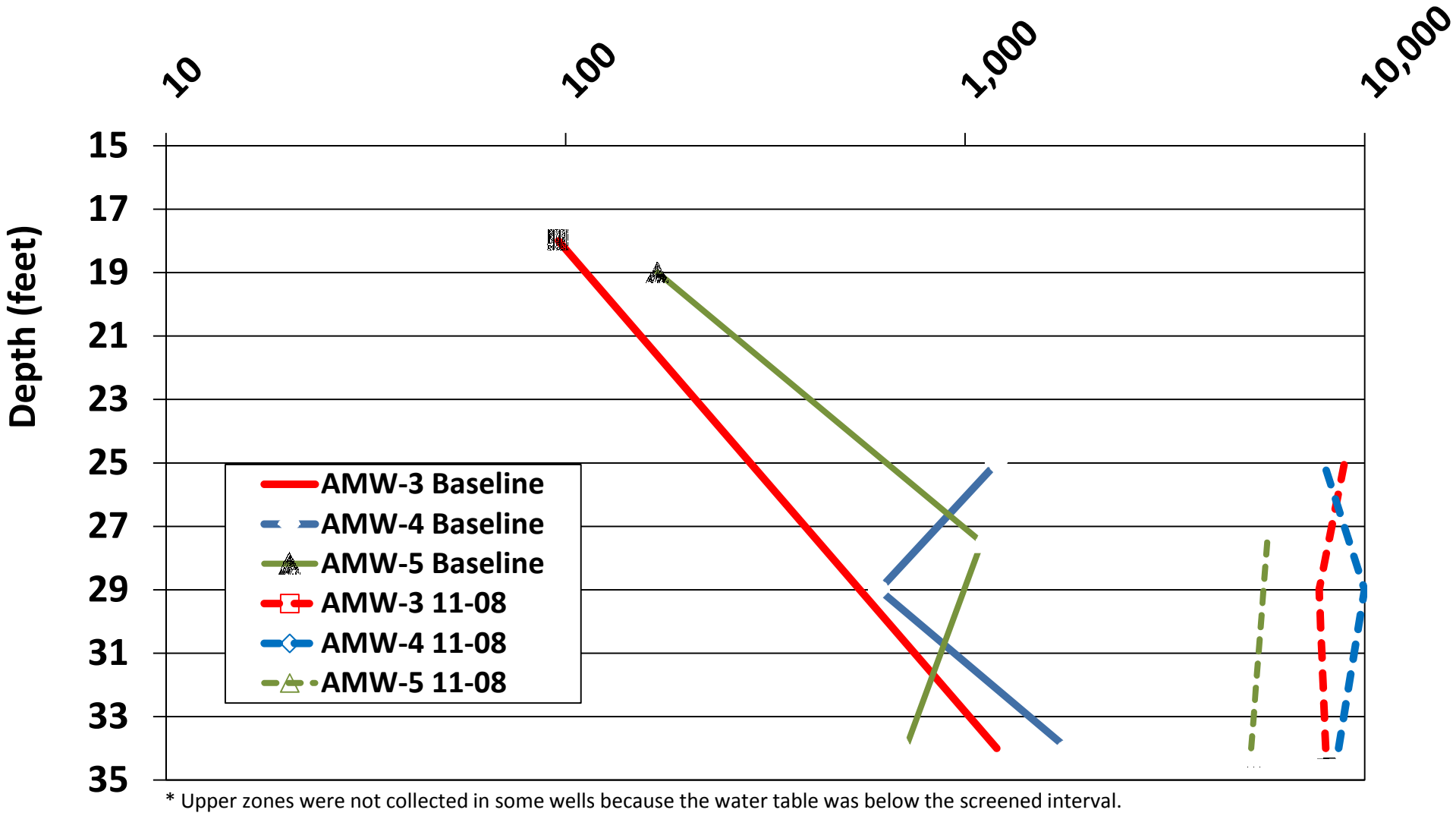
Scale in Feet
12.5 Feet 0 25 Feet

N W E S

CDM

Figure 2
November 2008 VOC Concentrations

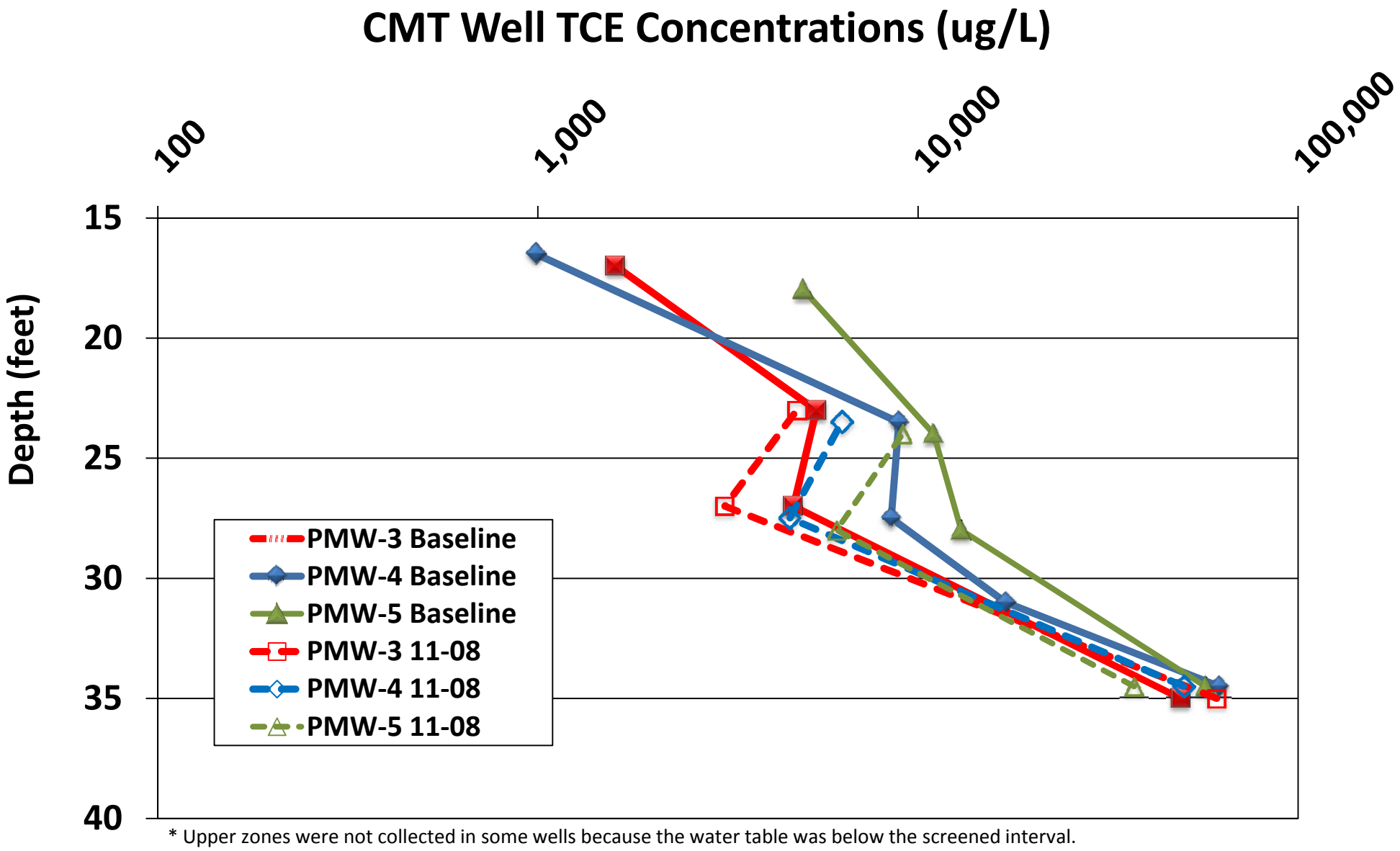
Project ER-0513
Naval Weapons Station Seal Beach
Site 70
Seal Beach, California



* Upper zones were not collected in some wells because the water table was below the screened interval.

Figure 3
Active Cell Vertical TCE Profiles
Project ER-0513
Naval Weapons Station Seal Beach
Site 70
Seal Beach, California

CDM



* Upper zones were not collected in some wells because the water table was below the screened interval.

Figure 4
Passive Cell Vertical TCE Profiles
Project ER-0513
Naval Weapons Station Seal Beach
Site 70
Seal Beach, California

CDM

Tables

Well ID	Well Type	Screen Interval (ft bgs)
Active Recirculation Cell		
AMW-1	Monitoring	15.1-35.1
AMW-2	Monitoring	15-35
AMW-3	CMT Z1	33-34
AMW-3	CMT Z2	28-29
AMW-3	CMT Z3	24-25
AMW-3	CMT Z4	17-18
AMW-4	CMT Z1	33-34
AMW-4	CMT Z2	28-29
AMW-4	CMT Z3	24-25
AMW-4	CMT Z4	18-19
AMW-5	CMT Z1	33-34
AMW-5	CMT Z2	26.5-27.5
AMW-5	CMT Z3	22-23
AMW-5	CMT Z4	18-19
AMW-6	Monitoring	15.5-35.5
AEW-1	Extraction	14.7-34.7
AEW-2	Extraction	15.3-35.3
AIW-1	Injection	15.6-35.6
AIW-2	Injection	15.5-35.5

Well ID	Well Type	Screen Interval (ft bgs)
Passive Cell		
PMW-1	Monitoring	15.3-35.3
PMW-2	Monitoring	15-35
PMW-3	CMT Z1	34-35
PMW-3	CMT Z2	26-27
PMW-3	CMT Z3	22-23
PMW-3	CMT Z4	16-17
PMW-4	CMT Z1	33.5-34.5
PMW-4	CMT Z2	30-31
PMW-4	CMT Z3	26.5-27.5
PMW-4	CMT Z4	22.5-23.5
PMW-4	CMT Z5	15.5-16.5
PMW-5	CMT Z1	33.5-34.5
PMW-5	CMT Z2	27-28
PMW-5	CMT Z3	23-24
PMW-5	CMT Z4	17-18
PMW-6	Monitoring	15-35
PMW-7	Monitoring	15-35
PMW-8	Monitoring	15-35
PMW-9	Monitoring	15-35
PIW-1	Injection	15-35
PIW-2	Injection	15-35
PIW-3	Injection	15-35

CMT- Continuous Multichannel Tubing
bgs - below ground surface

Table 1
Well Construction Details
Project ER-0513
Naval Weapons Station Seal Beach
Site 70
Seal Beach, California

Sample Location	Well Type	Nitrate (mg/L)			Ferrous Iron (mg/L)			Sulfate (mg/L)			Methane (ug/L)			COD (mg/L)		
		4/2008	11/2008	% Diff	4/2008	11/2008	% Diff	4/2008	11/2008	% Diff	4/2008	11/2008	% Diff	4/2008	11/2008	% Diff
Active Recirculation Cell																
AMW-1	Monitoring	0.89	0	-100%	0	0	NA	8,700	5,400	-38%	<5	<5	NA	34	32	-6%
AMW-2	Monitoring	0	0	NA	0	3.3	NA	7,400	2,600	-65%	<5	6	NA	40	47	18%
AMW-3	CMT Z1	0.21	0	-100%	0	0	NA	7,900	6,000	-24%	20	9	-55%	60	57	-5%
AMW-3	CMT Z2	NS	0	NA	NS	0	NA	NS	4,900	NA	NS	8	NA	NS	40	NA
AMW-3	CMT Z3	NS	0	NA	NS	0.70	NA	NS	3,700	NA	NS	13	NA	NS	38	NA
AMW-4	CMT Z1	0.14	0	-100%	0.17	3.10	1724%	6,300	5,900	-6%	21	9	-57%	48	47	-2%
AMW-4	CMT Z2	0.13	0	-100%	0	1.42	NA	6,900	3,300	-52%	41	10	-76%	44	36	-18%
AMW-4	CMT Z3	0	0	NA	0	0.37	NA	7,000	3,300	-53%	19	<5	NA	38	38	0%
AMW-5	CMT Z1	0.16	0	-100%	0.24	0	-100%	3,600	4,900	36%	28	14	-50%	42	47	12%
AMW-5	CMT Z2	0.18	0	-100%	0	3.23	NA	7,100	3,800	-46%	48	13	-73%	40	42	5%
AMW-6	Monitoring	0.35	0	-100%	0	0	NA	3,300	3,300	0%	40	33	-18%	58	47	-19%
AEW	Extraction	0.14	0	-14%	0	0	NA	1,600	1,500	-6%	140	100	-29%	28	34	21%
Passive Cell																
PMW-1	Monitoring	0.53	0.72	37%	0	0	NA	3,800	4,700	24%	360	14	-96%	28	25	-11%
PMW-2	Monitoring	0.04	0	-100%	0	2.19	NA	1,600	5,100	219%	2,300	71	-97%	18	120	567%
PMW-3	CMT Z1	0.03	0	-100%	0	1.92	NA	2,000	2,100	5%	220	220	0%	64	170	166%
PMW-3	CMT Z2	0.04	0	-100%	0	0.18	NA	4,200	3,800	-10%	80	86	8%	67	30	-55%
PMW-3	CMT Z3	0	0	NA	0	1.18	NA	3,900	4,400	13%	160	98	-39%	100	68	-32%
PMW-4	CMT Z1	0.09	0	-100%	0	0.62	NA	2,000	2,000	0%	180	290	61%	58	74	28%
PMW-4	CMT Z3	0	0	NA	0	0.10	NA	5,600	5,100	-9%	90	75	-17%	79	53	-33%
PMW-4	CMT Z4	0	0	NA	0	0.12	NA	5,000	4,400	-12%	190	130	-32%	68	57	-16%
PMW-5	CMT Z1	0.57	0	-100%	0	0	NA	2,100	2,200	5%	130	270	108%	38	44	16%
PMW-5	CMT Z2	0	0	NA	0	0.09	NA	5,700	6,000	5%	60	57	-5%	100	95	-5%
PMW-5	CMT Z3	0	0	NA	0.02	0.70	4567%	5,800	5,700	-2%	70	83	19%	87	83	-5%
PMW-6	Monitoring	0.10	0	-100%	0	0.99	NA	3,000	3,300	10%	170	130	-24%	56	78	39%
PMW-7	Monitoring	0.03	0	-100%	0	1.94	NA	3,000	2,600	-13%	210	140	-33%	50	1,100	2100%
PMW-8	Monitoring	0	0	NA	0	3.07	NA	2,400	1,900	-21%	430	150	-65%	46	1,400	2943%
PMW-9	Monitoring	0.01	0	-100%	0	0	NA	1,100	3,000	173%	2,800	370	-87%	16	13	-19%
PIW-1	Injection	0.11	0	-100%	0	0.02	NA	3,400	2,200	-35%	15	94	527%	28	99	254%
PIW-2	Injection	0.13	0	-100%	0	2.92	NA	3,900	600	-85%	230	6	-97%	71	4,900	6801%
PIW-3	Injection	0	0	NA	0	3.30	NA	3,100	15	-100%	150	14	-91%	30	5,700	18900%

NS - Not sampled during this event
NA - Percent difference not calculated
CMT - Continuous multichannel tubing
'<' - Below the reporting limit

Z1 is the deepest channel of each CMT well, Z3 is the shallowest. Not all channels were able to be sampled because thewater level was below the bottom of the channel.

Table 2
Electron Acceptor and Donor Results
Project ER-0513
Naval Weapons Station Seal Beach
Site 70
Seal Beach, California

Sample Location	Well Type	PCE (ug/L)		TCE (ug/L)		c-1,2-DCE (ug/L)		Vinyl Chloride (ug/L)	
		4/2008	11/2008	4/2008	11/2008	4/2008	11/2008	4/2008	11/2008
Active Recirculation Cell									
AMW-1	Monitoring	*BDL*	*BDL*	2,100	8,100	83	990	*BDL*	*BDL*
AMW-2	Monitoring	*BDL*	*BDL*	3,450	1,300	630	8,400	BDL	35
AMW-3	CMT Z1	*BDL*	*BDL*	1,200	8,000	32	1,900	*BDL*	*BDL*
AMW-3	CMT Z2	*NS*	*BDL*	*NS*	7,700	*NS*	1,300	*NS*	*BDL*
AMW-3	CMT Z3	*NS*	*BDL*	*NS*	8,900	*NS*	780	*NS*	*BDL*
AMW-4	CMT Z1	*BDL*	*BDL*	1,800	8,600	86	1,300	*BDL*	*BDL*
AMW-4	CMT Z2	*BDL*	*BDL*	610	10,000	9	1,700	*BDL*	*BDL*
AMW-4	CMT Z3	*BDL*	*BDL*	1,200	7,900	49	1,100	*BDL*	*BDL*
AMW-5	CMT Z1	*BDL*	*BDL*	710	5,200	14	650	*BDL*	*BDL*
AMW-5	CMT Z2	*BDL*	*BDL*	1,100	5,700	21	5,200	*BDL*	*BDL*
AMW-6	Monitoring	*BDL*	*BDL*	140,000	120,000	*BDL*	*BDL*	*BDL*	*BDL*
AEW	Extraction	*BDL*	*BDL*	10,000	35,000	1,900	1,700	*BDL*	*BDL*
Passive Cell									
PMW-1	Monitoring	*19*	*BDL*	1,150	1,600	49	64	*BDL*	*BDL*
PMW-2	Monitoring	*33*	*BDL*	28	3,000	3	65	*BDL*	*BDL*
PMW-3	CMT Z1	*BDL*	*BDL*	49,000	61,000	*BDL*	*BDL*	*BDL*	*BDL*
PMW-3	CMT Z2	*BDL*	7.5	4,700	3,100	90	69	*BDL*	*BDL*
PMW-3	CMT Z3	20	16	5,400	4,800	98	51	*BDL*	*BDL*
PMW-4	CMT Z1	*BDL*	*BDL*	62,000	50,000	*BDL*	*BDL*	*BDL*	*BDL*
PMW-4	CMT Z3	*BDL*	*BDL*	8,500	4,600	85	96	*BDL*	*BDL*
PMW-4	CMT Z4	*BDL*	21	8,900	6,300	77	86	*BDL*	*BDL*
PMW-5	CMT Z1	*BDL*	*BDL*	57,000	37,000	*BDL*	*BDL*	*BDL*	*BDL*
PMW-5	CMT Z2	*BDL*	15	13,000	6,100	*BDL*	86	*BDL*	*BDL*
PMW-5	CMT Z3	*BDL*	*BDL*	11,000	9,100	90	72	*BDL*	*BDL*
PMW-6	Monitoring	*BDL*	*BDL*	11,000	9,700	51	80	*BDL*	*BDL*
PMW-7	Monitoring	*BDL*	*BDL*	17,000	9,600	76	59	*BDL*	*BDL*
PMW-8	Monitoring	*BDL*	*BDL*	15,000	8,500	*120*	*BDL*	*BDL*	*BDL*
PMW-9	Monitoring	*BDL*	*BDL*	840	1,500	18	31	*BDL*	*BDL*
PIW-1	Injection	*BDL*	38	2,600	54	61.0	3.6	*BDL*	*BDL*
PIW-2	Injection	*BDL*	*BDL*	20,000	240	*BDL*	3.9	*BDL*	*BDL*
PIW-3	Injection	*BDL*	*BDL*	11,000	270	82	260	*BDL*	*BDL*

PCE - tetrachloroethene
TCE - trichloroethene
c-DCE - cis-1,2-dichloroethene
CMT - Continuous Multichannel Tubing
ug/L - micrograms per liter
BDL - below detection limits
NS - Not Sampled

Table 3
VOC Results
Project ER-0513
Naval Weapons Station Seal Beach
Site 70
Seal Beach, California

Sample ID	DNA ng/L groundwater	Universal PCR#	*Dehalococcoides* 16S rRNA copy/L groundwater*			*Dehalococcoides* tceA copy/L groundwater*			*Dehalococcoides* bvcA copy/L groundwater*			*Dehalococcoides* vcrA copy/L		
ACTIVE RECIRCULATION CELL														
AMW1	1028	+		ND			ND			ND			ND	
AMW2	4715	+	*3.36E+03*	±	8.10E+02	*2.36E+03*	±	4.70E+02	*4.60E+02*	±	4.70E+02		ND	
AMW3-Z1	417	+		ND			ND			ND			ND	
AMW3-Z2	1073	+		ND			ND			ND			ND	
AMW3-Z3	1940	+		ND			ND			ND			ND	
AMW4-Z1	2258	+	*2.07E+03*	±	3.99E+02	*2.15E+03*	±	5.59E+02	*4.00E+02*	±	2.06E+02		ND	
AMW4-Z2	2463	+		ND			ND			ND			ND	
AMW4-Z3	2293	+		ND			ND			ND			ND	
AMW5-Z1	989	+		ND			ND			ND			ND	
AMW5-Z2	5718	-		ND			ND			ND			ND	
AMW6	375	+		ND			ND			ND			ND	
AEW	293	+	1.60E+04	±	3.53E+02		ND			ND			ND	
PASSIVE CELL														
PMW1	350	+		ND			ND			ND			ND	
PMW2	6877	+		ND			ND			ND			ND	
PMW3-Z1	6807	+		ND			ND			ND			ND	
PMW3-Z2	2319	+		ND			ND			ND			ND	
PMW3-Z3	887	-		ND			ND			ND			ND	
PMW4-Z1	5816	+		ND			ND			ND			ND	
PMW4-Z3	3435	+		ND			ND			ND			ND	
PMW4-Z4	4258	+		ND			ND			ND			ND	
PMW5-Z1	1813	+		ND			ND			ND			ND	
PMW5-Z2	7000	+		ND			ND			ND			ND	
PMW5-Z3	12813	+		ND			ND			ND			ND	
PMW6	1976	+		ND			ND			ND			ND	
PMW7	10500	+		ND			ND			ND			ND	
PMW8	8711	+		ND			ND			ND			ND	
PMW9	478	-		ND			ND			ND			ND	
PIW1	2414	-		ND			ND			ND			ND	
PIW2	19167	+		ND			ND			ND			ND	
PIW3	30973	+		ND			ND			ND			ND	

*: Cells highlighted in yellow and in italics indicate that the value presented is below the reporting limit.

#: a '+' sign indicates that amplification of Bacteria was successful, and a '-' sign indicates that amplification was not successful.

ND: indicates sample was non-detect for the target.

Table 4
qPCR DNA Results
Project ER-0513
Naval Weapons Station Seal Beach
Site 70
Seal Beach, California

CDM

Appendix C
Site Photographs

Picture 1. AIW-2 well.

Picture 2. CMT Well.

Picture 3. Injection system control panel.

Picture 4. Dosatron setup.

Picture 5. Extraction piping daylighting.

Picture 6. Extraction piping daylighting.

Picture 7. Extraction well trench.

Picture 8. Normal monitoring well completion.

Picture 9. Peristaltic pump for groundwater purging.

Picture 10. Peristaltic pump sampling setup.

Picture 11. Piping to AIW-1.

Picture 12. Piping to AIW-2.

Picture 13. Piping between injection and extraction wells.

Picture 14. Piping between injection and extraction wells.

Picture 15. Groundwater purge setup with YSI.

Picture 16. Purging groundwater into bucket.

Picture 17. Sample collection.

Picture 18. Surge tank and control panel front.

Picture 19. Surge tank and control panel front.

Picture 20. Surge tank and control panel side.

Picture 21. Treatment compound area.

Picture 22. Treatment compound area.

Picture 23. Treatment compound area.

Picture 24. YSI with flow-thru cell for groundwater purging.

Appendix D
Laboratory Study Reports

Final Report

Microcosm Study

With Groundwater from

Naval Weapons Station Seal Beach Site, Irvine CA

Wells EW-70-01 & MW-70-27

received 2/9/06

Subcontract No.: 6225-001-002-AL

July 7, 2006

Prepared for:

Ryan A. Wymore, P.E. WymoreRA@cdm.com
and
Kent Sorenson, Ph.D. P.E
CDM
1331 17th Street, Suite 1100
Denver, CO 80202

Prepared by:
Bioremediation Consulting Inc
39 Clarendon St, Watertown MA 02472
ph 617-923-0976 fx -0959 bioremediation@bciLabs.com

Final Report of Microcosm Study
with Groundwater from Naval Weapons Station Seal Beach Site
Irvine CA, Wells EW-70-01 & MW-70-27 received 2/9/06
Subcontract No.: 6225-001-002-AL

July 7, 2006

Contents

Summary: Purpose, Approach, Results, Conclusions	3
Groundwater Characteristics	4
Methods	4
Results	5
Data Tables and Figures	7

Abbreviations

TCE, trichloroethene	DCE, cis-dichloroethene	VC, chloroethene
Ethe, ethene	Meth, methane	SO_4, sulfate
Ac, acetate	Lac, lactate	Pro, propionate
Bu, butyrate	NH_4-N ammonia nitrogen	PO_4 phosphate
YE, yeast extract	B_{12}, vitamin B_{12}	

Microcosm Study
with Groundwater from Naval Weapons Station Seal Beach Site
Wells EW-70-01 & MW-70-27

Summary

Purpose and Approach.

The purpose of this microcosm test was to determine whether two of BCI's bioaugmentation cultures could achieve dechlorination in well samples from the Seal Beach Site.

CDM selected two wells for testing (1) EW-70-01, which had a high chloride content of 2,200 mg/L and high sulfate content of 1,650 mg/L, and (2) MW-70-27, which had high chloride of 4,400 mg/L and extremely high sulfate of 9,300 mg/L. Both wells contained total chlorinated ethene concentrations of less than 30 mg/L.

BCI selected two of its *D.ethenogenes* cultures for testing; Culture "S" (a TCE-degrader) and Culture "B" (a mixed chloroethene-degrader), both of which had capabilities with high chloride concentrations. Both cultures were augmented with a sulfate-reducing culture active at high sulfate concentrations.

Anaerobic microcosms were constructed to test each culture with each groundwater sample, using whey as donor (food source), and adding small amounts of minerals needed by bacteria (ammonia and phosphate) as well as yeast extract and vitamin B_{12}. Killed control microcosms were also constructed for each well sample. Microcosms were monitored by removing small samples and analyzing for chlorinated organics and ethene by gas chromatography, and organic acids and sulfate by capillary ion electrophoresis.

Results and Conclusions

For EW-70-01, which contained 'only' 1,650 mg/L sulfate and 2,200 mg/L chloride, BCI Cultures "S" and "B" were equally successful in dechlorinating 16 mg/L TCE and 6 mg/L cDCE completely to ethene in 112 days.

For MW-70-27, which contained very high sulfate of 9,270 mg/L and very high chloride of 4,350 mg/L, Culture "S" succeeded in dechlorinating 73% of the 26 mg/L TCE in 112 days, whereas Culture "B" dechlorinated less than 1 % of the initial TCE to ethene. Therefore, Culture "S" appears to be the better choice for MW-70-27.

The utilization of whey was highly efficient in both ground waters, resulting in very little accumulation of organic acids, mainly due to the utilization of both lactate and acetate by the sulfate-reducing bacteria, and both propionate and butyrate by the organic-acid-oxidizers in the dechlorinating cultures.

Sample Receipt and Groundwater Characteristics

Samples. Groundwater used in this microcosm study was collected on 2/7/06 at Naval Weapons Station Seal Beach Site from MW-70-27 and EW-70-01 into 1 L serum bottles which had been filled with Argon and contained FeS reducing agent to give 0.25 mM. The samples were received 2/9/06. The EW-70-01 sample contained some black solids, indicating that anaerobic conditions had been maintained during sampling and shipping, and received 0.05 mM additional reducing agent. Samples from MW-70-27 arrived having an orange precipitate, indicating that the groundwater was aerobic. These samples received 0.44 mM additional reducing agent to create anaerobic conditions.

Groundwater Characteristics. Results of Groundwater analysis on are given in Table A. The absence of organic acids indicates that both well areas may be donor-limited, while the presence of ammonia and phosphate indicate that these areas are not mineral-limited. The presence of VC in EW-70-01 indicates that there may have been DCE-dechlorinating bacteria (*D. ethenogenes*) in this well area in the past, or that these organisms may currently be present up-gradient. The presence in MW-70-27 of ammonia, rather than nitrate, indicates that the area is at least slightly anaerobic.

Table A. Seal Beach Site Groundwater Characteristics, 2/9/06, **mg/L**

MG/L	meth	ethe	VC	cDCE	TCE	Cl	SO_4	organic acids	NO_3	NH_4-N	PO_4	pH
EW-70-01	.11	.01	.180	6.2	16	2,200	1,650	0	0	.1	.15	6.7
MW-70-27	.02	0	.005	0.2	29	4,350	9,270	0	0	.3	.88	7.0

Methods

Microcosm Construction and Maintenance. Microcosms were constructed by transferring 100 ml of groundwater to 160 ml serum bottles using anaerobic technique, were sealed with Teflon-coated rubber septa affixed with crimped caps, and were overpressurized with 5 cc anoxic gas. Controls were killed by lowering the pH to 3. Microcosms were maintained in darkness, with aqueous portion in contact with the septa, at 22 $\pm 1^{o}$C, and were shaken 3 times per week.

Amendments. Live microcosms received amendment stock solutions which were prepared using anaerobic procedures, and added by syringe to microcosms, giving 40 mg/L ammonia-nitrogen, 60 mg/L phosphate, 50 mg/L yeast extract, and 50 ppb vitamin B_{12}. Whey (aqueous) was received from a dairy, titrated to pH 8.8, made anaerobic, and stored frozen. Whey was added to microcosms in small increments as needed.

Day 1, Bioaugmenting with Sulfate-Reducing Bacteria: In order to lower the ORP to the level required by dechlorinating bacteria, the microcosms were bioaugmented with a BCI culture of salt-tolerant sulfate-reducers.

Days 8 and 23, Bioaugmenting with D.Ethenogenes. On day 8, one microcosm for each well received 0.3 ml of BCI Culture "S", and the second microcosm for each well received 0.3 ml of BCI Culture "B". This bioaugmentation was repeated on Day 23.

Maintenance: During the test, organic acids were monitored, and additional donor was added as needed to maintain detectable propionate, lactate, and/or butyrate. EW-70-01 microcosms received 0.4 ml whey on days 0, 8, 23, 50, 67, and 0.1 ml on day 81. MW-70-27 microcosms received 0.4 ml whey on days 0, 8, 23, 50, 67, and 0.5 ml on days 81, 88, and 96.

Removal of H_2S. Because H_2S resulting from sulfate reduction was removed by adding FeCl to precipitate FeS, subsequently requiring the addition of OH to re-adjust pH. This procedure is not necessary in situ, as metals in the soil will react with the sulfide. Starting on day 53, 16.8 mM FeCl were added to EW-70-01, and 23.5 mM FeCl were added to MW-70-27.

Microcosm Monitoring.

Methane, ethene, and chlorinated compounds were monitored by removing 100 µL samples of microcosm headspace and injecting into a HP 5890 gas chromatograph according to EPA Method 5021A. Standards were prepared similarly, and analyzed in the same manner as samples. ChemStation software was used to calculate response factors and quantitate results. Concentrations reported are those that would be present if each compound were completely in the aqueous phase (not partially in the headspace).

Nitrate, Sulfate and organic acids were determined by removing 100 µL aqueous samples and analyzing by capillary ion electrophoresis according to EPA Method 6500 (which does not separate lactate and propionate). Compounds were identified by retention time ratio in comparison with standards analyzed with each batch. Response factors were calculated and results quantified by Millennium software. pH was determined by removing 150 µL aqueous samples by syringe and measured with a ThermoOrion model 290A pH meter and a Sure-flow Ross semi-micro electrode.

Results and Discussion:

EW-70-01and MW-70-27 results are presented in Table 1 & Figure 1, and Table 2 & Figure 2 respectively.

Controls: The concentrations of contaminants and daughter products in the killed controls for either EW-70-0 or MW-70-27 did not change during the 112 day test period.

Utilization of Whey in Ground Water. Whey is initially broken down to a mixture of organic acids, formate, acetate, propionate, lactate, and butyrate. Acetate and lactate can be utilized by sulfate-reducing bacteria. Propionate and butyrate are further broken down to acetate, CO_2, and H_2, which is the donor used by dechlorinating bacteria.

EW-70-01 Results (Initial 1,600 mg/L SO_4 , 16 mg/L TCE, 6 mg/L cDCE)

EW-70-01 with Culture "S"

During the first three weeks, 300 mg/L of sulfate were reduced, and 20% of the TCE was dechlorinated to cDCE (a step which does not require *D. ethenogenes*). By day 112, the remaining sulfate was reduced and all remaining TCE had been dechlorinated to cDCE, then to VC and finally to Ethene.

EW-70-01 with Culture "B"

During the first three weeks, 270 mg/L Sulfate were reduced and no significant dechlorination occurred. Subsequently, by day 112, all of the remaining sulfate was reduced, and all of the TCE, DCE, and VC had been dechlorinated to ethene.

Utilization of Whey in EW-70-01

During the initial stage of sulfate reduction, acetate accumulated, indicating that sulfate-reducing bacteria were converting Lactate to acetate. Subsequently, acetate was utilized by the sulfate-reducers. Propionate and butyrate were apparently utilized to produce H_2 so quickly, that detectable concentrations were seen only on days 7 and 21 with culture S, and on day 109 with culture B. After dechlorination was complete, methane generation increased.

Culture Selection for EW-70-01

The two BCI Cultures, "S" and "B", dechlorinated TCE and cDCE in EW-70-01 with equal success.

MW-70-27 Results (Initial 9,270 mg/L SO_4 , 29 mg/L TCE, 0.2 mg/L cDCE)

MW-70-27 with Culture "S"

By day 21, about 400 mg/L sulfate had been reduced, and all TCE had been dechlorinated to cDCE. Subsequently, by day 112, additional 3,000 mg/L sulfate had been reduced and all cDCE had been dechlorinated to 73 % ethene and 27 % VC, with dechlorination continuing.

MW-70-27 with Culture "B"

By day 21, about 260 mg/L sulfate had been reduced, and all of the TCE had been dechlorinated to cDCE. Subsequently, by day 112, additional 3,000 mg/L sulfate had been reduced, but only 21% of the cDCE had been dechlorinated (to VC).

Utilization of Whey in MW-70-27

With both Culture "S" and Culture "B", acetate accumulated initially, but was subsequently utilized. Organic acids from whey were utilized too quickly to accumulate.

Culture Selection for MW-70-27

In the high-chloride, high-sulfate groundwater, Culture "S" succeeded in dechlorinating 73% of the 26 mg/L TCE in 112 days, whereas Culture "B" dechlorinated less than 1 % of the initial TCE to ethene. Therefore, Culture "S" appears to be the better choice for MW-70-27.

Seal Beach Site 70 Project Quantitative PCR Analytical Summary

31 January, 2007

Overview:

The objective of this project was to detect the number of *Dehalococcoides sp.* (DHC) 16S rRNA gene copies and reductase functional genes (*tceA*, *vcrA*, and *bvcA* copies) contained in groundwater collected from the Seal Beach Site 70 site, Seal Beach, CA, using quantitative polymerase chain reaction (QPCR). The client is CDM. Table 1 describes the sample matrix and the condition of the samples upon arrival to the analytical laboratory.

Table 1. Description of Seal Beach Site 70 samples and volume filtered for DNA extraction.

Well Location	Matrix/Date Sampled	Condition Received/ Observations	Volume
MW70-27	Groundwater	Dry ice preserved filter	18
EW70-01	Groundwater	Dry ice preserved filter	27

The two samples arrived in good condition within the specified holding time. Upon arrival, the samples were frozen for storage at -80°C until the DNA extraction was performed. Following DNA extraction, the samples were first subjected to polymerase chain reaction (PCR) using universal bacterial probes in order to verify that amplifiable DNA was present in the samples. In addition, for the 16S rRNA gene, a "nested" QPCR approach can be applied in which the universal bacterial PCR-amplified DNA is used as the template in a QPCR reaction. Although the results from the nested QPCR cannot be quantified per se, they can be used to lower the detect limit for the QPCR in order to determine if the *Dehalococcoides* 16S rRNA gene is present at concentrations lower than the method detect limit (MDL) using the groundwater DNA extractions. The results of these studies are described here.

Methods:

DNA Extraction: 250 to 500 mL of groundwater was filtered in the field using sterile 0.2-µm acetate filters and filter apparatus (Table 1). The filters were frozen at -80°C and then shattered. Next, each sample tube was amended with 2 mL of DNA-free water, vortexed vigorously for 5 minutes, and the liquid volume was partitioned into DNA extraction tubes. DNA extractions were performed using the Bio101 DNA Extraction Kit according to the manufacturer's instructions. Community DNA was eluted in nuclease-free water (50 µL) and stored at -20°C.

Amplification of Bacteria: The PCR was used to amplify nearly full-length 16S rRNA genes from *Bacteria*. Each 25-µL PCR reaction included 0.4 mg mL-1 molecular-grade BSA (Sigma Chemicals), 1X PCR buffer (Promega), 1.5 mM $MgCl_2$, 0.5 µM each forward and reverse primer (Invitrogen), 1 U Taq DNA polymerase (Promega), 0.2 mM each dNTP (Invitrogen), 1 µL template DNA, and molecular-grade water (Promega). Amplification was performed on a PerkinElmer Model 9600 thermocycler using the following regime: 94°C (5 min) followed by 25 cycles of 94°C (1 min), 53.5°C (1 min), and 72°C (1 min). The reaction was finished with an additional 7 minutes at 72°C. PCR products were examined in a 1.2% agarose gel stained with ethidium bromide to confirm specificity of the amplification reactions.

Detection of Dehalococcoides: The QPCR methods for assessing the 16S rRNA gene, and the reductase genes *tceA*, *bvcA*, and *vcrA*, are very sensitive in detecting specific DNA fragments. The detection limit for the methods used is approximately 2 gene copies per µL of the DNA extraction. The reporting limit is 50 gene copies per µL of the DNA extraction.

A mixed laboratory culture containing *Dehalococcoides* was used to obtain the quantitative standard used in these analyses. Plasmid DNA containing DNA inserts of targets 16S rRNA gene, *tceA*, *bvcA*, and *vcrA* from *Dehalococcoides* were purified and quantified fluorometrically. Based on the known size of the plasmid and insert, DNA concentrations were converted to insert copy numbers. A dilution series spanning seven orders of magnitude was generated using known concentrations of each plasmid. Amplification and detection of the DNA was performed using the Cepheid System. The acceptance criterion for the standard curve is a linear R^2 value of greater than 0.995.

TaqMan Protocol. The 16S rRNA gene QPCR reaction was performed using TaqMan chemistry (Applied Biosystems). All reagents and materials used in the QPCR amplification are purchased from Applied Biosystems. Reaction volumes of 25 µL contained forward and reverse primers at a concentration of 700 nM, a probe at a concentration of 200 nM, 1 x TaqMan Universal PCR Master Mix, and 5 µL of sample DNA. The settings for cycle number and reaction conditions used for all runs were 95°C for 10 minutes, and 45 cycles of 95°C for 15 seconds and 58°C for 1 minute. Standards and unknowns were run in triplicate to ensure reproducibility. Cycle thresholds (C_t) were set to minimize the standard deviation of standard curve triplicate C_t values, and also to obtain a standard curve slope as close to negative 3.5 as possible.

SYBR Green Protocol. The functional reductase genes *tceA*, *bvcA*, and vcrA were assessed using SYBR green chemistry (Applied Biosystems). Reaction volumes of 25 µL contained forward and reverse primers at a concentration of 700 nM, a probe at a concentration of 200 nM, 1 x SYBR green Universal PCR Master Mix, and 5 µL of sample DNA. The settings for cycle number and reaction conditions used for all runs were 95°C for 10 minutes, and 45 cycles of 95°C for 15 seconds and 58°C for 1 minute. Standards and unknowns were run in triplicate to ensure reproducibility. Cycle thresholds (C_t) were set to minimize the standard deviation of standard curve triplicate C_t values, and also to obtain a standard curve slope as close to negative 3.5 as possible.

Results:

The two samples arrived at the lab in good condition frozen with dry ice still in the cooler. The filters were immediately placed in a -80°C freezer and stored until the DNA extraction was performed. Table 2 summarizes the results of the project samples. The DNA extraction negative control and all PCR negative controls did not amplify any product. In addition, all calibration control checks were within acceptable values.

Table 2. Results of molecular analyses for Seal Beach site samples.

Well Location	DNA (ng/L groundwater)	PCR Bacteria[#]	*Dehalococcoides* 16S rDNA (copy/L groundwater)*	*Dehalococcoides* tceA (copy/L groundwater)*	*Dehalococcoides* bvcA (copy/L groundwater)*	*Dehalococcoides* vcrA (copy/L groundwater)*
MW70-27	10	+	0.00 (+)[#]	0.00	0.00	0.00
EW70-01	26	+	$4.59 \times 10^2 \pm 2.91 \times 10^2$	$7.50 \times 10^{3\wedge}$	$8.95 \times 10^{3\wedge}$	0.00

* : a * indicates that the value presented is below the reporting limit.
\# : a '+' sign indicates that amplification of *Bacteria* and *Dehalococcoides* (in the nested QPCR) was successful, and a '-' sign indicates that amplification was not successful.
^ these samples were not run in triplicate due to limited volumes of DNA.

The DNA concentration of the DNA extraction in ng/L of groundwater is reported as an indicator of relative biomass levels for the samples so that relative comparisons can be made. The DNA concentrations ranged from 10 ng/L groundwater for sample MW70-27 to 26 ng/L for sample EW70-01 (Table 2). This indicates very low biomass in the samples, especially considering the large volumes of groundwater that were filtered. All DNA extractions yielded sufficient DNA to amplify *Bacteria*, confirming that despite the very low biomass, amplifiable DNA was obtained from each sample.

DHC was detected in the DNA extraction for sampleEW70-01 at low concentrations (459 16S rRNA gene copies/L groundwater) and was not detected in sample MW70-27 (Table 2). However, DHC was detected in sample MW70-27 in the nested QPCR, which indicates that this microbe is present but below the MDL using the DNA extraction alone. In addition, the reductase genes *tceA* and *bvcA* were detected in the samples, but *vcrA* was not.

Evaluation of 16S rRNA gene and vcrA gene Sequences Obtained from Seal Beach Site 70 and Three Bioaugmentation Cultures

Introduction:

Molecular analyses was conducted to evaluate *Dehalococcoides* spp. found in the Seal Beach Site 70 site with those found in various bioaugmenation cultures including BCI, Shaw and KB-1. These analyses were conducted in order to determine if indigenous *Dehalococcoides* spp. could be distinguished from those present in several bioaugmentation cultures for the purpose of tracking the growth and transport of the bioaugmented *Dehalococcoides* spp. following inoculation into groundwater at the Seal Beach Site 70 site.

Several methods were used to evaluate *Dehalococcoides* including quantitative PCR analysis and clone library analysis to evaluate various *Dehalococcoides* genes including the 16S rRNA gene, and functional reductase genes *vcrA*, *bvcA* and *tceA*. The following describes clone library analysis used to evaluate the 16S rRNA gene of the Seal Beach Site 70 *Dehalococcoides* and the three bioagumentation cultures and evaluation of *vcrA* sequence analysis of the Shaw and KB-1 bioaugmentation cultures.

Methods:

Clone libraries were constructed for samples EW70-01, BCI and the Shaw bioaugmentation culture to determine the 16S rRNA gene sequence composition of *Dehalococcoides* spp. amplified using primers Fp DHC 1/Rp DHC 1377 shown in Table 1 (Hendrickson et al 2002). (Table 1). In addition, a clone library was constructed using the Shaw bioaugmentation culture using vcrA reductase-gene specific primers. The TOPO® TA kit with TOP10 chemically competent E. coli was used for clone library construction (Invitrogen™) and the clone libraries were constructed according to the manufacturers instructions.

The clones were selected by blue-white screening, and only those colonies containing plasmids with inserts (white colonies) were selected and plated on LB/SGAL/Kan media plates (Sigma-Aldrich). Plasmids were purified from 5 transformants from each of the 16S rRNA libraries and the vcrA reductase library. Plasmid DNA was extracted and purified from cultures of each clone grown in 1 mL of TPYNG medium containing kanamycin using the QIAprep Spin Miniprep Kit (Qiagen). The purified plasmids were sequenced using primers identified in Table X. to obtain greater than 2X average coverage of the entire insert. Sequencing reactions employed the ABI PRISM BigDye Terminator Cycle Sequencing Ready Reaction Kit (Applied Biosystems) and Model 3100 Automated DNA Sequencer (Applied Biosystems).

The sequences were assembled and aligned using BioEdit software. Sequences were initially aligned against known sequences (GenBank database) using the BLAST tool provided by the National Center for Biotechnology Information. For the 16S rRNA clone libaries a multiple sequence alignment of clones from the Seal Beach site, and the three bioaugmentation cultures was performed with the European Molecular Biology

Laboratory-European Bioinformatics Institute (EMBL-EBI) Clustal W alignment tool. For the vcrA library, the vcrA sequence for *Dehalococcoides* strain VS, an uncultured vcrA sequence and the KB-1 published vcrA sequence were downloaded and included in an alignment with the clones obtained from the Shaw clone library constructed here. The 16S rRNA gene and vcrA gene sequence similarity was then assessed for the sequences within the two alignments. In addition, base pair mismatches were identified and evaluated.

Table 1. Primer targets used for generation of clone libraries.

Primer	Target	Sequence	Use	Reference
Fp DHC 1	16S rDNA DHC	5'GATGAACGCTAGCGGCG3'	Cloning/ Sequencing	Hendrickson et al 2002
Rp DHC 1377	16S rDNA DHC	5'GGTTGGCACATCGACTTCAA3'	Cloning/ Sequencing	Hendrickson et al 2002
Rp DHC 692	16S rDNA DHC	5'TCAGTGACAACCTAGAAAAC3'	Sequencing	Hendrickson et al 2002
515F	16S rDNA Universal Bacteria	5'GTGCCAGCMGCCGCGGTAA3'	Sequencing	
vcrABF	vcrA reductase	5'CTATGAAGGCCCTCCAGATGC3'	Cloning/ Sequencing	Muller et al 2004
vcrABR	vcrA reductase	5'GTAACAGCCCCAATATGCAAGTA3'	Cloning/ Sequencing	Muller et al 2004
vcrAF	vcrA reductase	5'CTCGGCTACCGAACGGATT3'	Sequencing/QPCR	Lee et al 2006
vcrAR	vcrA reductase	5'GGGCAGGAGGATTGACACAT3'	Sequencing/QPCR	Lee et al 2006

Results:

16S rRNA gene analysis. In order to evaluate the utility of 16S rDNA methods for tracking *Dehalococcoides* populations indigenous to the Seal Beach site and those found in the bioaugmentation cultures, clone libraries were constructed from the Seal Beach Site 70 groundwater sample collected from well EW70-01, and from the bioaugmentation cultures obtained from BCI and Shaw. 16S rDNA sequences were obtained from five clones from the EW70-01 and BCI libraries and four clones from the Shaw library. The approximately 1300 bp DNA sequence obtained from each clone was initially aligned against known sequences using the BLAST tool (Table 2) in order to determine the closest match with sequences in the GenBank database. In addition to the sequences obtained from the libraries, an alignment was generated using a ClustalW algorithm (http://www.ebi.ac.uk/clustalw/) with published sequences from bioaugmentation culture KB-1 in order to determine the sequence similarity between the environmental clone sequences and those observed in the various bioaugmentation cultures (Table 3 and Figure 1).

Results from the 16S rDNA clone library GenBank analysis suggests that most of the *Dehalococcoides* spp. identified in the Seal Beach and bioaugmentation clone libraries were most closely related to *Dehalococcoides ethenogenes* strain 195, or *Dehalococcoides* sp. TM-EtOH (Table 2) with greater than 98-99% sequence similarity. In addition, the ClustalW alignment conducted with the generated clone sequences and two sequences published for the KB-1 culture (KB1-PCE and KB1-VC) suggests that all of the 16S rDNA sequences evaluated were 97% or greater to eachother (Table 2). The alignment shown in Figure 1 illustrates the DNA base pair differences between the sequences by highlighting them in yellow. These data illustrate that the *Dehalococcoides* spp. 16S rDNA sequences are highly similar, and while there are some regions between different sequences that are significantly different, it would be difficult to distinguish between the observed sequences found within the different bioaugmentation cultures and those indigenous to the Seal Beach site by 16S rDNA molecular analysis alone.

Table 2. Genebank results for the bacterial 16S rDNA clone library results for the Seal Beach site (EW70-01) sample and the bioaugmentation cultures BCI, and Shaw.

Name	Accession	Closest GenBank match	Base pair % similarity
EW07-01#8	CP000027.1	Dehalococcoides ethenogenes 195, complete genome	1265/1281 (98%),
EW-70-01#6	AY882433.1	Dehalococcoides sp. TM-EtOH 16S ribosomal RNA gene, partial	1270/1279 (99%),
EW-70-01#7	AY882433.1	Dehalococcoides sp. TM-EtOH 16S ribosomal RNA gene, partial	1276/1278 (99%),
EW-70-01#2	CP000027.1	Dehalococcoides ethenogenes 195, complete genome	1286/1292 (99%),
EW-70-01#3	CP000027.1	Dehalococcoides ethenogenes 195, complete genome	1272/1275 (99%),
BCI #3	AF388530.1	Uncultured Dehalococcoides sp. clone DHC-asd 16S ribosomal RNA	1266/1276(99%),
BCI #17	AY882433.1	Dehalococcoides sp. TM-EtOH 16S ribosomal RNA gene, partial	1272/1277(99%),
BCI#15	CP000027.1	Dehalococcoides ethenogenes 195, complete genome	1271/1278 (99%),
BCI#1	CP000027.1	Dehalococcoides ethenogenes 195, complete genome	1256/1263 (99%),
BCI#16	CP000027.1	Dehalococcoides ethenogenes 195, complete genome	1273/1276 (99%
Shaw16s#1	CP000027.1	Dehalococcoides ethenogenes 195, complete genome	1006/1011 (99%),
Shaw16s#2	AY882433.1	Dehalococcoides sp. TM-EtOH 16S ribosomal RNA gene, partial	1277/1278 (99%),
Shaw16s#3	CP000027.1	Dehalococcoides ethenogenes 195, complete genome	278/1279 (99%),
Shaw16s#4	CP000027.1	Dehalococcoides ethenogenes 195, complete genome	1327/1331 (99%),

Table 3. Sequence Similarity of 16S rRNA gene sequences from BCI, Shaw, KB-1 and EW70-01.

SeqA	Name	Length(bp)	SeqB	Name	Length(bp)	Score (%)
1	BCI#1	1388	2	BCI#3	1386	97
1	BCI#1	1388	3	BCI#15	1336	98
1	BCI#1	1388	4	BCI#16	1388	98
1	BCI#1	1388	5	BCI#17	1386	98
1	BCI#1	1388	6	EW70-01#2	1388	98
1	BCI#1	1388	7	EW70-01#3	1388	98
1	BCI#1	1388	8	EW70-01#6	1386	98
1	BCI#1	1388	9	EW70-01#7	1387	98
1	BCI#1	1388	10	EW70-01#8	1373	98
1	BCI#1	1388	11	Shaw16s#1	1387	98
1	BCI#1	1388	12	Shaw16s#2	1388	98
1	BCI#1	1388	13	Shaw16s#3	1388	98
1	BCI#1	1388	14	Shaw16s#4	1279	98
1	BCI#1	1388	15	KB1-VC	1386	97
1	BCI#1	1388	16	KB1-PCE	1385	97
2	BCI#3	1386	3	BCI#15	1336	98
2	BCI#3	1386	4	BCI#16	1388	98
2	BCI#3	1386	5	BCI#17	1386	98
2	BCI#3	1386	6	EW70-01#2	1388	98
2	BCI#3	1386	7	EW70-01#3	1388	98
2	BCI#3	1386	8	EW70-01#6	1386	98
2	BCI#3	1386	9	EW70-01#7	1387	98
2	BCI#3	1386	10	EW70-01#8	1373	97
2	BCI#3	1386	11	Shaw16s#1	1387	98
2	BCI#3	1386	12	Shaw16s#2	1388	98
2	BCI#3	1386	13	Shaw16s#3	1388	98
2	BCI#3	1386	14	Shaw16s#4	1279	98
2	BCI#3	1386	15	KB1-VC	1386	98
2	BCI#3	1386	16	KB1-PCE	1385	98
3	BCI#15	1336	4	BCI#16	1388	99
3	BCI#15	1336	5	BCI#17	1386	98
3	BCI#15	1336	6	EW70-01#2	1388	98
3	BCI#15	1336	7	EW70-01#3	1388	99
3	BCI#15	1336	8	EW70-01#6	1386	98
3	BCI#15	1336	9	EW70-01#7	1387	99
3	BCI#15	1336	10	EW70-01#8	1373	98
3	BCI#15	1336	11	Shaw16s#1	1387	98
3	BCI#15	1336	12	Shaw16s#2	1388	99
3	BCI#15	1336	13	Shaw16s#3	1388	99
3	BCI#15	1336	14	Shaw16s#4	1279	99
3	BCI#15	1336	15	KB1-VC	1386	97
3	BCI#15	1336	16	KB1-PCE	1385	97
4	BCI#16	1388	5	BCI#17	1386	99
4	BCI#16	1388	6	EW70-01#2	1388	99
4	BCI#16	1388	7	EW70-01#3	1388	99
4	BCI#16	1388	8	EW70-01#6	1386	99
4	BCI#16	1388	9	EW70-01#7	1387	99
4	BCI#16	1388	10	EW70-01#8	1373	98
4	BCI#16	1388	11	Shaw16s#1	1387	99
4	BCI#16	1388	12	Shaw16s#2	1388	99
4	BCI#16	1388	13	Shaw16s#3	1388	99
4	BCI#16	1388	14	Shaw16s#4	1279	99

4	BCI#16	1388	15	KB1-VC	1386	98
4	BCI#16	1388	16	KB1-PCE	1385	97
5	BCI#17	1386	6	EW70-01#2	1388	99
5	BCI#17	1386	7	EW70-01#3	1388	99
5	BCI#17	1386	8	EW70-01#6	1386	99
5	BCI#17	1386	9	EW70-01#7	1387	99
5	BCI#17	1386	10	EW70-01#8	1373	98
5	BCI#17	1386	11	Shaw16s#1	1387	99
5	BCI#17	1386	12	Shaw16s#2	1388	99
5	BCI#17	1386	13	Shaw16s#3	1388	99
5	BCI#17	1386	14	Shaw16s#4	1279	99
5	BCI#17	1386	15	KB1-VC	1386	97
5	BCI#17	1386	16	KB1-PCE	1385	97
6	EW70-01#2	1388	7	EW70-01#3	1388	99
6	EW70-01#2	1388	8	EW70-01#6	1386	98
6	EW70-01#2	1388	9	EW70-01#7	1387	99
6	EW70-01#2	1388	10	EW70-01#8	1373	98
6	EW70-01#2	1388	11	Shaw16s#1	1387	99
6	EW70-01#2	1388	12	Shaw16s#2	1388	99
6	EW70-01#2	1388	13	Shaw16s#3	1388	99
6	EW70-01#2	1388	14	Shaw16s#4	1279	99
6	EW70-01#2	1388	15	KB1-VC	1386	97
6	EW70-01#2	1388	16	KB1-PCE	1385	97
7	EW70-01#3	1388	8	EW70-01#6	1386	99
7	EW70-01#3	1388	9	EW70-01#7	1387	99
7	EW70-01#3	1388	10	EW70-01#8	1373	98
7	EW70-01#3	1388	11	Shaw16s#1	1387	99
7	EW70-01#3	1388	12	Shaw16s#2	1388	99
7	EW70-01#3	1388	13	Shaw16s#3	1388	99
7	EW70-01#3	1388	14	Shaw16s#4	1279	99
7	EW70-01#3	1388	15	KB1-VC	1386	97
7	EW70-01#3	1388	16	KB1-PCE	1385	97
8	EW70-01#6	1386	9	EW70-01#7	1387	99
8	EW70-01#6	1386	10	EW70-01#8	1373	98
8	EW70-01#6	1386	11	Shaw16s#1	1387	98
8	EW70-01#6	1386	12	Shaw16s#2	1388	99
8	EW70-01#6	1386	13	Shaw16s#3	1388	99
8	EW70-01#6	1386	14	Shaw16s#4	1279	98
8	EW70-01#6	1386	15	KB1-VC	1386	97
8	EW70-01#6	1386	16	KB1-PCE	1385	97
9	EW70-01#7	1387	10	EW70-01#8	1373	98
9	EW70-01#7	1387	11	Shaw16s#1	1387	99
9	EW70-01#7	1387	12	Shaw16s#2	1388	99
9	EW70-01#7	1387	13	Shaw16s#3	1388	99
9	EW70-01#7	1387	14	Shaw16s#4	1279	99
9	EW70-01#7	1387	15	KB1-VC	1386	97
9	EW70-01#7	1387	16	KB1-PCE	1385	97
10	EW70-01#8	1373	11	Shaw16s#1	1387	98
10	EW70-01#8	1373	12	Shaw16s#2	1388	98
10	EW70-01#8	1373	13	Shaw16s#3	1388	99
10	EW70-01#8	1373	14	Shaw16s#4	1279	98
10	EW70-01#8	1373	15	KB1-VC	1386	97
10	EW70-01#8	1373	16	KB1-PCE	1385	97
11	Shaw16s#1	1387	12	Shaw16s#2	1388	99
11	Shaw16s#1	1387	13	Shaw16s#3	1388	99
11	Shaw16s#1	1387	14	Shaw16s#4	1279	99
11	Shaw16s#1	1387	15	KB1-VC	1386	97

11	Shaw16s#1	1387	16	KB1-PCE	1385	97
12	Shaw16s#2	1388	13	Shaw16s#3	1388	99
12	Shaw16s#2	1388	14	Shaw16s#4	1279	99
12	Shaw16s#2	1388	15	KB1-VC	1386	98
12	Shaw16s#2	1388	16	KB1-PCE	1385	98
13	Shaw16s#3	1388	14	Shaw16s#4	1279	99
13	Shaw16s#3	1388	15	KB1-VC	1386	98
13	Shaw16s#3	1388	16	KB1-PCE	1385	97
14	Shaw16s#4	1279	15	KB1-VC	1386	98
14	Shaw16s#4	1279	16	KB1-PCE	1385	98
15	KB1-VC	1386	16	KB1-PCE	1385	99

Figure 1. Sequence Alignment 16S rDNA for the Shaw, BCI, KB1 and EW70-01.

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EW70-01#8       -CCCTTGATGAACGCTAGCGGCGTGCCTTATGCATGCAAGTCGAACGG-TCTTAAGCAAT 58
Shaw16s#1       GCCCTTGATGAACGCTAGCGGCGTGCCTTATGCATGCAAGTCGAACGG-TCTTAAGCAAT 59
BCI#1           -CCCTTGATGAACGCTAGCGGCGTGCCTTATGCATGCAAGTCGAACGG-TCTTAAGCAAT 58
BCI#16          ---CTTGATGAACGCTAGCGGCGTGCCTTATGCATGCAAGTCGAACGG-TCTTAAGCAAT 56
EW70-01#6       ---CTTGATGAACGCTAGCGGCGTGCCTTATGCATGCAAGTCGAACGG-TCTTAAGCAAT 56
EW70-01#3       --CCTTGATGAACGCTAGCGGCGTGCCTTATGCATGCAAGTCGAACGG-TCTTAAGCAAT 57
BCI#17          -CCCTTGATGAACGCTAGCGGCGTGCCTTATGCATGCAAGTCGAACGG-TCTTAAGCAAT 58
Shaw16s#2       -CCCTTGATGAACGCTAGCGGCGTGCCTTATGCATGCAAGTCGAACGG-TCTTAAGCAAT 58
EW70-01#7       -CCCTTGATGAACGCTAGCGGCGTGCCTTATGCATGCAAGTCGAACGG-TCTTAAGCAAT 58
Shaw16s#3       -CCCTTGATGAACGCTAGCGGCGTGCCTTATGCATGCAAGTCGAACGG-TCTTAAGCAAT 58
BCI#15          -CCCTTGATGAACGCTAGCGGCGTGCCTTATGCATGCAAGTCGAACGG-TCTTAAGCAAT 58
EW70-01#2       -CCCTTGATGAACGCTAGCGGCGTGCCTTATGCATGCAAGTCGAACGGGTCTTAAGCA-T 58
Shaw16s#4       ----------------------------------------------------------AT 2
BCI#3           ---CTTGATGAACGCTAGCGGCGTGCCTTATGCATGCGAGTCGAACGG-TCTTAAGCAAT 56
KB1-VC          ------GATGAACGCTAGCGGCGTGCCTTATGCATGCAAGTCGAACGG-TCTTAAGCAAT 53
KB1-PCE         ------GATGAACGCTAGCGGCGTGCCTTATGCATGCAAGTCGAACGG-TCTTAAGCAAT 53
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EW70-01#8       TAAGA-TAGTGGCAAACGGGTGAGTAACGCGTAAGTAACCTACCTCTAAGTGGGGGATAG 117
Shaw16s#1       TAAGA-TAGTGGCAAACGGGTGAGTAACGCGTAAGTAGCCTACCTCTAAGTGGGGGATAG 118
BCI#1           TAAGA-TAGTGGCAAACGGGTGAGTAACGCGTAAGTAACCTACCTCTAAGTGGGGGATAG 117
BCI#16          TAAGA-TAGTGGCAAACGGGTGAGTAACGCGTAAGTAACCTACCTCTAAGTGGGGGATAG 115
EW70-01#6       TAAGA-TAGTGGCAAACGGGTGAGTAACGCGTAAGTAACCTACCTCTAAGTGGGGGATAG 115
EW70-01#3       TAAGAATAGTGGCAAACGGGTGAGTAACGCGTAAGTAACCTACCTCTAAGTGGGGGATAG 117
BCI#17          TAAGA-TAGTGGCAAACGGGTGAGTAACGCGTAAGTAACCTACCTCTAAGTGGGGGATAG 117
Shaw16s#2       TAAGA-TAGTGGCAAACGGGTGAGTAACGCGTAAGTAGCCTACCTCTAAGTGGGGGATAG 117
EW70-01#7       TAAGA-TAGTGGCAAACGGGTGAGTAACGCGTAAGTAACCTACCTCTAAGTGGGGGATAG 117
Shaw16s#3       TAAGA-TAGTGGCAAACGGGTGAGTAACGCGTAAGTAACCTACCTCTAAGTGGGGGATAG 117
BCI#15          TAAGA-TAGTGGCAAACGGGTGAGTAACGCGTAAGTAACCTACCTCTAAGTGGGGGATAG 117
EW70-01#2       TAAGA-TAGTGGCTAACGGGTGAGTAACGCGTAAGTAACCTACCTCTAAGTGGGGGATAG 117
Shaw16s#4       TAAGA-TAGTGGCAAACGGGTGAGTAACGCGTAAGTAACCTACCTCTAAGTGGGGGATAG 61
BCI#3           TAAGA-TAGTGGCAAACGGGTGAGTAACGCGTAAGTAACCTACCTCTAAGTGGGGGATAG 115
KB1-VC          TAAGA-TAGTGGCGAACGGGTGAGTAACGCGTAAGTAACCTACCTCTAAGTGGGGGATAG 112
KB1-PCE         TAAGA-TAGTGGCGAACGGGTGAGTAACGCGTAAGTAACCTACCTCTAAGTGGGGGATAG 112
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EW70-01#8       CTTCGGGAAACTGAAGGTAATACCGCATGTGATGGGCTGACATAAGTCGGTTCATTAAAG 177
Shaw16s#1       CTTCGGGAAACTGAAGGTAATACCGCATGTGATGGGCTGACATAAGTCGGTTCATTAAAG 178
BCI#1           CTTCGGGAAACTGAAGGTAATACCGCATGTGATGGACTGACATAAGTCGGTTCATTAAAG 177
BCI#16          CTTCGGGAAACTGAAGGTAATACCGCATGTGATGGGCTGACATAAGTCGGTTCATTAAAG 175
EW70-01#6       CTTCGGGAAACTGAAGGTAATACCGCATGTGATGGGCTGACATAAGTCGGTTCATTAAAG 175
EW70-01#3       CTTCGGGAAACTGAAGGTAATACCGCATGTGATGGGCTGACATAAGTCGGTTCATTAAAG 177
BCI#17          CTTTGGGAAACTGAAGGTAATACCGCATGTGATGGGCTGACATAAGTCGGTTCATTAAAG 177
Shaw16s#2       CTTCGGGAAACTGAAGGTAATACCGCATGTGATGGGCTGACATAAGTCGGTTCATTAAAG 177
EW70-01#7       CTTCGGGAAACTGAAGGTAATACCGCATGTGATGGGCTGACATAAGTCGGTTCATTAAAG 177
Shaw16s#3       CTTCGGGAAACTGAAGGTAATACCGCATGTGATGGGCTGACATAAGTCGGTTCATTAAAG 177
BCI#15          CTTCGGGAAACTGAAGGTRATACCGCATGTGATGGGCTGACATAAGTCGGTTCATTAAAG 177
EW70-01#2       CTTCGGGAAACTGAAGGTAATACCGCATGTGATGGGCTGACATAAGTCGGTTCACTAAAG 177
Shaw16s#4       CTTCGGGAAACTGAAGGTAATACCGCATGTGATGGGCTGACATAAGTCGGTTCATTAAAG 121
BCI#3           CTTCGGGAAACTGAAGGTAATACCGCATGTGGTGGGCCGACATATGTTGGTCCACTAAAG 175
KB1-VC          CTTCGGGAAACTGAAGGTAATACCGCATGTGGTGGGCCGACATATGTTGGTTCACTAAAG 172
KB1-PCE         CTTCGGGAAACTGAAGGTAATACCGCATGTGGTGGACCGACATATGTTGGTTCACTAAAG 172
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EW70-01#8       CCGCAAGGTGCTTGGTGAGGGGCTTGCGTCCG-ATTAGCTAGTTGGTGGGGTAATGGCCT 236
Shaw16s#1       CCGCAAGGTGCTTGGTGAGGGGCTTGCGTCCG-ATTAGCTAGTTGGTGGGGTAATGGCCT 237
BCI#1           CCGCAAGGTGCTTGGTGAGGGGCTTGCGTCCG-ATTAGCTAGTTGGTGGGGTAATGGCCT 236
BCI#16          CCGCAAGGTGCTTGGTGAGGGGCTTGCGTCCG-ATTAGCTAGTTGGTGGGGTAATGGCCT 234
EW70-01#6       CCGCAAGGTGCTTGGTGAGGGGCTTGCGTGAGGAATAAATAGTTGGTGGGGTAATGGCCT 235
EW70-01#3       CCGCAAGGTGCTTGGTGAGGGGCTTGCGTCCG-ATTAGCTAGTTGGTGGGGTAATGGCCT 236
BCI#17          CCGCAAGGTGCTTGGTGAGGGGCTTGCGTCCG-ATTAGCTAGTTGGTGGGGTAATGGCCT 236
Shaw16s#2       CCGCAAGGTGCTTGGTGAGGGGCTTGCGTCCG-ATTAGCTAGTTGGTGGGGTAATGGCCT 236
EW70-01#7       CCGCAAGGTGCTTGGTGAGGGGCTTGCGTCCG-ATTAGCTAGTTGGTGGGGTAATGGCCT 236
Shaw16s#3       CCGCAAGGTGCTTGGTGAGGGGCTTGCGTCCG-ATTAGCTAGTTGGTGGGGTAATGGCCT 236
BCI#15          CCGCAAGGTGCTTGGTGAGGGGCTTGCGTCCG-ATTAGCTAGTTGGTGGGGTAATGGCCT 236
EW70-01#2       CCGCAAGGTGCTTGGTGAGGGGCTTGCGTCCG-ATTAGCTAGTTGGTGGGGTAATGGCCT 236
Shaw16s#4       CCGCAAGGTGCTTGGTGAGGGGCTTGCGTCCG-ATTAGCTAGTTGGTGGGGTAATGGCCT 180
BCI#3           CCGTAAGGCGCTTGGTGAGGGGCTTGCGTCCG-ATTAGCTAGTTGGTGGGGTAATGGCCT 234
KB1-VC          CCGTAAGGCGCTTGGTGAGGGGCTTGCGTCCG-ATTAGCTAGTTGGTGGGGTAATGGCCT 231
KB1-PCE         CCGTAAGGCGCTTGGTGAGGGGCTTGCGTCCG-ATTAGCTAGTTGGTGGGGTAATGGCCT 231
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EW70-01#8       ACCAAGGCTTCGATCGGTAGCTGGTCTGAGAGGATGATCAGCCACACTGGGACTGAGACA 296
Shaw16s#1       ACCAAGGCTTCGATCGGTAGCTGGTCTGAGAGGATGATCAGCCACACTGGGACTGAGACA 297
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BCI#1          ACCAAGGCTTCGATCGGTAGCTGATCTGAGAGGATGATCAGCCACACTGGGACTGAGACA 296
BCI#16         ACCAAGGCTTCGATCGGTAGCTGGTCTGAGAGGATGATCAGCCACACTGGGACTGAGACA 294
EW70-01#6      ACCAAGGCTTCGATCGGTAGCTGGTCTGAGAGGATGATCAGCCACACTGGGACTGAGACA 295
EW70-01#3      ACCAAGGCTTCGATCGGTAGCTGGTCTGAGAGGATGATCAGCCACACTGGGACTGAGACA 296
BCI#17         ACCAAGGCTTCGATCGGTAGCTGGTCTGAGAGGATGATCAGCCACACTGGGACTGAGACA 296
Shaw16s#2      ACCAAGGCTTCGATCGGTAGCTGGTCTGAGAGGATGATCAGCCACACTGGGACTGAGACA 296
EW70-01#7      ACCAAGGCTTCGATCGGTAGCTGGTCTGAGAGGATGATCAGCCACACTGGGACTGAGACA 296
Shaw16s#3      ACCAAGGCTTCGATCGGTAGCTGGTCTGAGAGGATGATCAGCCACACTGGGACTGAGACA 296
BCI#15         ACCAAGGCTTCGATCGGTAGCTGGTCTGAGAGGATGATCAGCCACACTGGGACTGAGACA 296
EW70-01#2      ACCAAGGCTTCGATCGGTAGCTGGTCTGAGAGGATGATCAGCCACACTGGGACTGAGACA 296
Shaw16s#4      ACCAAGGCTTCGATCGGTAGCTGGTCTGAGAGGATGATCAGCCACACTGGGACTGAGACA 240
BCI#3          ACCAAGGCTTCGATCGGTAGCTGGTCTGAGAGGATGATCAGCCACACTGGGACTGAGACA 294
KB1-VC         ACCAAGGCTTCGATCGGTAGCTGGTCTGAGAGGATGATCAGCCACACTGGGACTGAGACA 291
KB1-PCE        ACCAAGGCTTCGATCGGTAGCTGGTCTGAGAGGATGATCAGCCACACTGGGACTGAGACA 291
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EW70-01#8      CGGCCCAGACTCCTACGGGAGGCAGCAGCAAGGAATCTTGGGCAA----CGAAAGCCTGA 352
Shaw16s#1      CGGCCCAGACTCCTACGGGAGGCAGCAGCAAGGAATCTTGGGCAATGGGCGAAAGCCTGA 357
BCI#1          CGGCCCAGACTCCTACGGGAGGCAGCAGCAAGGAATCTTGGGCAATGGGCGAAAGCCTGA 356
BCI#16         CGGCCCAGACTCCTACGGGAGGCAGCAGCAAGGAATCTTGGGCAATGGGCGAAAGCCTGA 354
EW70-01#6      CGGCCCAGACTCCTACGGGAGGCAGCAGCAAGGAATCTTGGGCAATGGGCGAAAGCCTGA 355
EW70-01#3      CGGCCCAGACTCCTACGGGAGGCAGCAGCAAGGAATCTTGGGCAATGGGCGAAAGCCTGA 356
BCI#17         CGGCCCAGACTCCTACGGGAGGCAGCAGCAAGGAATCTTGGGCAATGGGCGAAAGTCTGA 356
Shaw16s#2      CGGCCCAGACTCCTACGGGAGGCAGCAGCAAGGAATCTTGGGCAATGGGCGAAAGCCTGA 356
EW70-01#7      CGGCCCAGACTCCTACGGGAGGCAGCAGCAAGGAATCTTGGGCAATGGGCGAAAGCCTGA 356
Shaw16s#3      CGGCCCAGACTCCTACGGGAGGCAGCAGCAAGGAATCTTGGGCAATGGGCGAAAGCCTGA 356
BCI#15         CGGCCCAGACTCCTACGGGAGGCAGCAGCAAGGAATCTTGGGCAATGGGCGAAAGCCTGA 356
EW70-01#2      CGGCCCAGACTCCTACGGGAGGCAGCAGCAAGGAATCTTGGGCAATGGGCGAAAGCCTGA 356
Shaw16s#4      CGGCCCAGACTCCTACGGGAGGCAGCAGCAAGGAATCTTGGGCAATGGGCGAAAGCCTGA 300
BCI#3          CGGCCCAGACTCCTACGGGAGGCAGCAGCAAGGAATCTTGGGCAATGGGCGGAAGCCTGA 354
KB1-VC         CGGCCCAGACTCCTACGGGAGGCAGCAGCAAGGAATCTTGGGCAATGGGCGAAAGCCTGA 351
KB1-PCE        CGGCCCAGACTCCTACGGGAGGCAGCAGCAAGGAATCTTGGGCAATGGGCGAAAGCCTGA 351
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EW70-01#8      CCCAGCAACGCCGCGTGAGGGATGAAAGGCTTTCGGGTGTAAACCTCTTTTCACAGGGA 412
Shaw16s#1      CCCAGCACGCCCGCGTGAGGGATGAA-GGCTTTCGGGTTGTAAACCTCTTTTCACAGGGA 416
BCI#1          CCCAGCAACGCCGCGTGAGGGATGAA-GGCTTTCGGGTTGTAAACCTCTTTTCACAGGGA 415
BCI#16         CCCAGCAACGCCGCGTGAGGGATGAA-GGCTTTCGGGTTGTAAACCTCTTTTCACAGGGA 413
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EW70-01#6       CCCAGCAACACCGCGTGAGGGATGAA-GGCTTTCGGGTTGTAAACCTCTTTTCACAGGGA 414
EW70-01#3       CCCAGCAACGCCGCGTGAGGGATGAA-GGCTTTCGGGTTGTAAACCTCTTTTCACAGGGA 415
BCI#17          CCCAGCAACGCCGCGTGAGGGATGAA-GGCTTTCGGGTTGTAAACCT-TTTTCACAGGGA 414
Shaw16s#2       CCCAGCAACGCCGCGTGAGGGATGAA-GGCTTTCGGGTTGTAAACCTCTTTTCACAGGGA 415
EW70-01#7       CCCAGCAACGCCGCGTGAGGGATGAA-GGCTTTCGGGTTGTAAACCTCTTTTCACAGGGA 415
Shaw16s#3       CCCAGCAACGCCGCGTGAGGGATGAA-GGCTTTCGGGTTGTAAACCTCTTTTCACAGGGA 415
BCI#15          CCCAGCAACGCCGCGTGAGGGATGAA-GGCTTTCGGGTTGTAAACCTCTTTTCGCAGGGA 415
EW70-01#2       CCCAGCAACGCCGCGTGAGGGATGAA-GGCTTTCGGGTTGTAAACCTCTTTTCACAGGGA 415
Shaw16s#4       CCCAGCAACGCCGCGTGAGGGATGAA-GGCTTTCGGGTTGTAAACCTCTTTTCACAGGGA 359
BCI#3           CCCAGCAACGCCGCGTGAGGGATGAA-GGCTTTCGGGTTGTAAACCTCTTTTCATAGGGA 413
KB1-VC          CCCAGCAACGCCGCGTGAGGGATGAA-GGCTTTCGGGTTGTAAACCTCTTTTCATAGGGA 410
KB1-PCE         CCCAGCAACGCCGCGTGAGGGATGAA-GGCTTTCGGGTTGTAAACCTCTTTTCATAGGGA 410
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EW70-01#8       AGAATAATGACGGTACCTGTGGAATAAGCCTCGGCTAACTACGTGCCAGCAGCCGCGGTA 472
Shaw16s#1       AGAATAATGACGGTACCTGTGGAATAAGCTTCGGCTAACTACGTGCCAGCAGCCGCGGTA 476
BCI#1           AGAATAATGTCGGTACCTGTGGAATAAGCTTCGGCTAACTACGTGCCAGCAGCCGCGGTA 475
BCI#16          AGAATAATGACGGTACCTGTGGAATAAGCTTCGGCTAACTACGTGCCAGCAGCCGCGGTA 473
EW70-01#6       A-AATAATGACGGTACCTGTGGAATAAGCTTCGGCTAACTACGTGCCAGCAGCCGCGGTA 473
EW70-01#3       AGAATAATGACGGTACCTGTGGAATAAGCTTCGGCTAACTACGTGCCAGCAGCCGCGGTA 475
BCI#17          AGAATAATGACGGTACCTGTGGAATAAGCTTCGGCTAACTACGTGCCAGCAGCCGCGGTA 474
Shaw16s#2       AGAATAATGACGGTACCTGTGGAATAAGCTTCGGCTAACTACGTGCCAGCAGCCGCGGTA 475
EW70-01#7       AGAATAATGACGGTACCTGTGGAATAAGCTTCGGCTAACTACGTGCCAGCAGCCGCGGTA 475
Shaw16s#3       AGAATAATGACGGTACCTGTGGAATAAGCTTCGGCTAACTACGTGCCAGCAGCCGCGGTA 475
BCI#15          AGAATAATGACGGTACCTGTGGAATAAGCTTCGGCTAACTACGTGCCAGCAGCCGCGGTA 475
EW70-01#2       AGAATAATGACGGTACCTGTGGAATAAGCTTCGGCTAACTACGTGCCAGCAGCCGCGGTA 475
Shaw16s#4       AGAATAATGACGGTACCTGTGGAATAAGCTTCGGCTAACTACGTGCCAGCAGCCGCGGTA 419
BCI#3           AGAATAATGACGGTACCTGTGGAATAAGCTTCGGCTAACTACGTGCCAGCAGCCGCGGTA 473
KB1-VC          AGAATAATGACGGTACCTGTGGAATAAGCTTCGGCTAACTACGTGCCAGCAGCCGCGGTA 470
KB1-PCE         AGAATAATGACGGTACCTGTGGAATAAGCTTCGGCTAACTACGTGCCAGCAGCCGCGGTA 470
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EW70-01#8       ATACGTAGGAAGCAAGCGTTATCCGGATTTATTGGGCGTAAAGTGAGCGTAGGTGGTCTT 532
Shaw16s#1       ATACGTAGGAAGCAAGCGTTATCCGGATTTATTGGGCGTAAAGTGAGCGTAGGTGGTCTT 536
BCI#1           ATACGTAGGAAGCAAGCGTTATCCGGATTTATTGGGCGTAAAGTGAGCGTAGGTGGTCTT 535
BCI#16          ATACGTAGGAAGCAAGCGTTATCCGGATTTATTGGGCGTAAAGTGAGCGTAGGTGGTCTT 533
EW70-01#6       ATACGTAGGAAGCAAGCGTTATCCGGATTTATTGGGCGTAAAGTGAGCGTAGGTGGTCTT 533
EW70-01#3       ATACGTAGGAAGCAAGCGTTATCCGGATTTATTGGGCGTAAAGTGAGCGTAGGTGGTCTT 535
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BCI#17          ATACGTAGGAAGCAAGCGTTATCCGGATTTATTGGGCGTAAAGTGAGCGTAGGTGGTCTT 534
Shaw16s#2       ATACGTAGGAAGCAAGCGTTATCCGGATTTATTGGGCGTAAAGTGAGCGTAGGTGGTCTT 535
EW70-01#7       ATACGTAGGAAGCAAGCGTTATCCGGATTTATTGGGCGTAAAGTGAGCGTAGGTGGTCTT 535
Shaw16s#3       ATACGTAGGAAGCAAGCGTTATCCGGATTTATTGGGCGTAAAGTGAGCGTAGGTGGTCTT 535
BCI#15          ATACGTAGGAAGCAAGCGTTATCCGGATTTATTGGGCGTAAAGTGGGCGTAGGTGGTCTT 535
EW70-01#2       ATACGTAGGAAGCAAGCGTTATCCGGATTTATTGGGCGTAAAGTGAGCGTAGGTGGTCTT 535
Shaw16s#4       ATACGTAGGAAGCAAGCGTTATCCGGATTTATTGGGCGTAAAGTGAGCGTAGGTGGTCTT 479
BCI#3           ATACGTAGGAAGCAAGCGTTATCCGGATTTATTGGGCGTAAAGTGAGCGTAGGTGGTCTT 533
KB1-VC          ATACGTAGGAAGCAAGCGTTATCCGGATTTATTGGGCGTAAAGTGAGCGTAGGTGGTCTT 530
KB1-PCE         ATACGTAGGAAGCAAGCGTTATCCGGATTTATTGGGCGTAAAGTGAGCGTAGGTGGTCTT 530
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EW70-01#8       TCAAGTTGGATGTGAAATTTCCCGGCTTAACCGGGACGTGTCATTCAATACTGTTGGACT 592
Shaw16s#1       TCAAGTTGGATGTGAAATTTCCCGGCTTAACCGGGACGTGTCATTCAATACTGTTGGACT 596
BCI#1           CCAAGTTGGATGTGAAATTTCCCGGCTTAGCCGGGACGTGTCATTCAATACTGTTGGACT 595
BCI#16          TCAAGTTGGATGTGAAATTTCCCGGCTTAACCGGGACGTGTCATTCAATACTGTTGGACT 593
EW70-01#6       TCAAGTTGGATGTGAAATTTCCCGGCTTAACCGGGACGTGTCATTCAATACTGTTGGACT 593
EW70-01#3       TCAAGTTGAATGTGAAATTTCCCGGCTTAACCGGGACGTGTCATTCAATACTGTTGGACT 595
BCI#17          TCAAGTTGGATGTGAAATTTCCCGGCTTAACCGGGACGTGTCATTCAATACTGTTGGACT 594
Shaw16s#2       TCAAGTTGGATGTGAAATTTCCCGGCTTAACCGGGACGTGTCATTCAATACTGTTGGACT 595
EW70-01#7       TCAAGTTGGATGTGAAATTTCCCGGCTTAACCGGGACGTGTCATTCAATACTGTTGGACT 595
Shaw16s#3       TCAAGTTGGATGTGAAATTTCCCGGCTTAACCGGGACGTGTCATTCAATACTGTTGGACT 595
BCI#15          TCAAGTTGGATGTGAAATTTCCCGGCTTAACCGGGACGAGTCATTCAATACTGTTGGACT 595
EW70-01#2       TCAAGTTGGATGTGAAATTTCCCGGCTTAACCGGGACGTGTCATCCAATACTGTTGGACT 595
Shaw16s#4       TCAAGTTGGATGTGAAATTTCCCGGCTTAACCGGGACGTGTCATTCAATACTGTTGGACT 539
BCI#3           TCAAGTTGGATGTGAAATTTCCCGGCTTAACCGGGACGTGTCATTCAATACTGTTGGACT 593
KB1-VC          TCAAGTTGGATGTGAAATTTCCCGGCTTAACCGGGACGAGTCATTCAATACTGTTGGACT 590
KB1-PCE         TCAAGTTGGA-GTGAAATTTCCCGGCTTAACCGGGACGAGTCATTCAATACTGTTGGACT 589
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EW70-01#8       AGAGTACAGCAGGAGAAAACGGAATTCCCGGTGTAGTGGTAAAATGCGTAGATATCGGGA 652
Shaw16s#1       AGAGTACAGCAGGAGAAAACGGAATTCCCGGTGTAGTGGTAAAATGCGTAGATATCGGGA 656
BCI#1           AGAGTACAGCAGGAGAAAACGGAATTCCCGGTGTAGTGGTAAAATGCGTAGATATCGGGA 655
BCI#16          AGAGTACAGCAGGAGAAAACGGAATTCCCGGTGTAGTGGTAAAATGCGTAGATATCGGGA 653
EW70-01#6       AGAGTACAGCAGGAGAAAACGGAATTCCCGGTGTAGTGGTAAAATGCGTAGATATCGGGA 653
EW70-01#3       AGAGTACAGCAGGAGAAAACGGAATTCCCGGTGTAGTGGTAAAATGCGTAGATATCGGGA 655
BCI#17          AGAGTACAGCAGGAGAAAACGGAATTCCCGGTGTAGTGGTAAAATGCGTAGATATCGGGA 654
Shaw16s#2       AGAGTACAGCAGGAGAAAACGGAATTCCCGGTGTAGTGGTAAAATGCGTAGATATCGGGA 655
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EW70-01#7       AGAGTACAGCAGGAGAAAACGGAATTCCCGGTGTAGTGGTAAAATGCGTAGATATCGGGA 655
Shaw16s#3       AGAGTACAGCAGGAGAAAACGGAATTCCCGGTGTAGTGGTAAAATGCGTAGATATCGGGA 655
BCI#15          AGAGTACAGCAGGAGTAAACGGAATTCCCGGTGTAGTGGTAAAATGCGKAGATATCGGGA 655
EW70-01#2       AGAGTACAGCAGGAGAAAACGGAATTCCCGGTGTAGTGGTAAAATGCGTAGATATCGGGA 655
Shaw16s#4       AGAGTACAGCAGGAGAAAACGGAATTCCCGGTGTAGTGGTAAAATGCGTAGATATCGGGA 599
BCI#3           AGAGTACAGCAGGAGAAAACGGAATTCCCGGTGTAGTGGTAAAATGCGTAGATATCGGGA 653
KB1-VC          AGAGTACAGCAGGAGAAAACGGAATTCCCGGTGTAGTGGTAAAATGCGTAGATATCGGGA 650
KB1-PCE         AGAGTACAGCAGGAGAAAACGGAATTCCCGGTGTAGTGGTAAAATGCGTAGATATCGGGA 649
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EW70-01#8       GGAACACCAGAGGCGAAGGCGGTTTTCTAGGTTGTCACTGACACTGAGGCTCGAAAGCGT 712
Shaw16s#1       GGAACACCAGAGGCGAAGGCGGTTTTCTAGGTTGTCACTGACACTGAGGCTCGAAAGCGT 716
BCI#1           GGAACACCAGAGGCGAAGGCGGTTTTCTAGGTTGTCACTGACACTGAGGCTCGAAAGCGT 715
BCI#16          GGAACACCAGAGGCGAAGGCGGTTTTCTAGGTTGTCACTGACACTGAGGCTCGAAAGCGT 713
EW70-01#6       GGAACACCAGAGGCGAAGGCGGTTTTCTAGGTTGTCACTGACACTGAGGCTCGAAAGCGT 713
EW70-01#3       GGAACACCAGAGGCGAAGGCGGTTTTCTAGGTTGTCACTGACACTGAGGCTCGAAAGCGT 715
BCI#17          GGAACACCAGAGGCGAAGGCGGTTTTCTAGGTTGTCACTGACGCTGAGGCTCGAAAGCGT 714
Shaw16s#2       GGAACACCAGAGGCGAAGGCGGTTTTCTAGGTTGTCACTGACACTGAGGCTCGAAAGCGT 715
EW70-01#7       GGAACACCAGAGGCGAAGGCGGTTTTCTAGGTTGTCACTGACACTGAGGCTCGAAAGCGT 715
Shaw16s#3       GGAACACCAGAGGCGAAGGCGGTTTTCTAGGTTGTCACTGACACTGAGGCTCGAAAGCGT 715
BCI#15          GGAACACCAGAGGCGAAGGCGGTTTTCTAGGTTGTCACTGACACTGAGGCTCGAAAGCGT 715
EW70-01#2       GGAACACCAGAGGCGAAGGCGGTTTTCTAGGTTGTCACTGACACTGAGGCTCGAAAGCGT 715
Shaw16s#4       GGAACACCAGAGGCGAAGGCGGTTTTCTAGGTTGTCACTGACACTGAGGCTCGAAAGCGT 659
BCI#3           GGAACACCAGAGGCGAAGGCGGTTTTCTAGGTTGTCACTGACACTGAGGCTCGAAAACGT 713
KB1-VC          GGAACACCAGAGGCGAAGGCGGTTTTCTAGGTTGTCACTGACACTGAGGCTCGAAAGCGT 710
KB1-PCE         GGAACACCAGAGGCGAAGGCGGTTTTCTAGGTTGTCACTGACACTGAGGCTCGAAAGCGT 709
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EW70-01#8       GGGGAGCGAACAGAATTAGATACTCTGGTAGTCCACGCCTTAAACTATGGACACTAGGTA 772
Shaw16s#1       GGGGAGCGAACAGAATTAGATACTCTGGTAGTCCACGCCTTAAACTATGGACACTAGGTA 776
BCI#1           GGGGAGCGAACAGAATTAGATACTCTGGTAGTCCACGCCTTAAACTATGGACACTAGGTA 775
BCI#16          GGGGAGCGAACAGAATTAGATACTCTGGTAGTCCACGCCTTAAACTATGGACACTAGGTA 773
EW70-01#6       GGGGAGCGAACAGAATTAGATACTCTGGTAGTCCACGCCTTAAACTATGGACACTAGGTA 773
EW70-01#3       GGGGAGCGAACAGAATTAGATACTCTGGTAGTCCACGCCTTAAACTATGGACACTAGGTA 775
BCI#17          GGGGAGCGAACAGAATTAGATACTCTGGTAGTCCACGCCTTAAACTATGGACACTAGGTA 774
Shaw16s#2       GGGGAGCGAACAGAATTAGATACTCTGGTAGTCCACGCCTTAAACTATGGACACTAGGTA 775
EW70-01#7       GGGGAGCGAACAGAATTAGATACTCTGGCAGTCCACGCCTTAAACTATGGACACTAGGTA 775
Shaw16s#3       GGGGAGCGAACAGAATTAGATACTCTGGTAGTCCACGCCTTAAACTATGGACACTAGGTA 775
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BCI#15          GGGGAGCGAACAGAATTAGATACTCTGGTAGTCCACGCCTTAAACTATGGACACTAGGTA 775
EW70-01#2       GGGGAGCGAACAGAATTAGATACTCTGGTAGTCCACGCCTTAAACTATGGACACTAGGTA 775
Shaw16s#4       GGGGAGCGAACAGAATTAGATACTCTGGTAGTCCACGCCTTAAACTATGGACACTAGGTA 719
BCI#3           GGGGAGCGAACAGAATTAGATACTCTGGTAGTCCACGCATTAAACTATGGACACTAGGTA 773
KB1-VC          GGGGAGCGAACAGAATTAGATACTCTGGTAGTCCACGCCTTAAACTATGGACACTAGGTA 770
KB1-PCE         GGGGAGCGAACAGAATTAGATACTCTGGTAGTCCACGCCTTAAACTATGGACACTAGGTA 769
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EW70-01#8       TAGGGAGTATCGACCCTCTCTGTGCCGAAGCTAACGCTTTAAGTGTCCCGCCTGGGGAGT 832
Shaw16s#1       TAGGGAGTATCGACCCTCTCTGTGCCGAAGCTAACGCTTTAAGTGTCCCGCCTGGGGAGT 836
BCI#1           TAGGGAGTATCGACCCTCTCTGTGCCGAAGCTAACGCTTTAAGTGTCCCGCCTGGGGAGT 835
BCI#16          TAGGGAGTATCGACCCTCTCTGTGCCGAAGCTAACGCTTTAAGTGTCCCGCCTGGGGAGT 833
EW70-01#6       TAGGGAGTATCGACCCTCTCTGTGCCGAAGCTAACGCTTTAAGTGTCCCGCCTGGGGAGT 833
EW70-01#3       TAGGGAGTATCGACCCTCTCTGTGCCGAAGCTAACGCTTTAAGTGTCCCGCCTGGGGAGT 835
BCI#17          TAGGGAGTATCGACCCTCTCTGTGCCGAAGCTAACGCTTTAAGTGTCCCGCCTGGGGAGT 834
Shaw16s#2       TAGGGAGTATCGACCCTCTCTGTGCCGAAGCTAACGCTTTAAGTGTCCCGCCTGGGGAGT 835
EW70-01#7       TAGGGAGTATCGACCCTCTCTGTGCCGAAGCTAACGCTTTAAGTGTCCCGCCTGGGGAGT 835
Shaw16s#3       TAGGGAGTATCGACCCTCTCTGTGCCGAAGCTAACGCTTTAAGTGTCCCGCCTGGGGAGT 835
BCI#15          TAGGGAGTATCGACCCTCTCTGTGCCGAAGCTAACGCTTTAAGTGTCCCGCCTGGGGAGT 835
EW70-01#2       TAGGGAGTATCGACCCTCTCTATGCCGAAGCTAACGCTTTAAGTGTCCCGCCTGGGGAGT 835
Shaw16s#4       TAGGGAGTATCGACCCTCTCTGTGCCGAAGCTAACGCTTTAAGTGTCCCGCCTGGGGAGT 779
BCI#3           TAGGGAGTATCGACCCTCTCTGTGCCGAAGCTAACGCTTTAAGTGTCCCGCCTGGGGAGT 833
KB1-VC          TAGGGAGTATCGACCCTCTCTGTGCCGAAGCTAACGCTTTAAGTGTCCCGCCTGGGGAGT 830
KB1-PCE         TAGGGAGTATCGACCCTCTCTGTGCCGAAGCTAACGCTTTAAGTGTCCCGCCTGGGGAGT 829
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EW70-01#8       ACGGTCGCAAGGCTAAAACTCAAAGGAATTGACGGGGGCCCGCACAAGCAGCGGAGCGTG 892
Shaw16s#1       ACGGTCGCAAGGCTAAAGCTCAAAGGAATTGACGGGGGCCCGCACAAGCAGCGGAGCGTG 896
BCI#1           ACGGTCGCAGGGCTAAAACTCAAAGGAATTGACGGGGGCCCGCACAAGCAGCGGAGCGTG 895
BCI#16          ACGGTCGCAAGGCTAAAACTCAAAGGAATTGACGGGGGCCCGCACAAGCAGCGGAGCGTG 893
EW70-01#6       ACGGTCGCAAGGCTAAAACTCAAAGGAATTGACGGGGGCCCGCACAAGCAGCGGAGCGTG 893
EW70-01#3       ACGGCCGCAAGGCTAAAACTCAAAGGAATTGACGGGGGCCCGCACAAGCAGCGGAGCGTG 895
BCI#17          ACGGTCGCAAGGCTAAAACTCAAAGGAATTGACGGGGGCCCGCACAAGCAGCGGAGCGTG 894
Shaw16s#2       ACGGTCGCAAGGCTAAAACTCAAAGGAATTGACGGGGGCCCGCACAAGCAGCGGAGCGTG 895
EW70-01#7       ACGGTCGCAAGGCTAAAACTCAAAGGAATTGACGGGGGCCCGCACAAGCAGCGGAGCGTG 895
Shaw16s#3       ACGGTCGCAAGGCTAAAACTCAAAGGAATTGACGGGGGCCCGCACAAGCAGCGGAGCGTG 895
BCI#15          ACGGTCGCAAGGCTAAAACTCAAAGGAATCGACGGGGGCCCGCACAAGCAGCGGAGCGTG 895
EW70-01#2       ACGGTCGCAAGGCTAAAACTCAAAGGAATTGACGGGGGCCCGCACAAGCAGCGGAGCGTG 895
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Shaw16s#4       ACGGTCGCAAGGCTAAAACTCAAAGGAATTGACGGGGGCCCGCACAAGCAGCGGAGCGTG 839
BCI#3           ACGGTCGCAAGGCTAAAACTCAAAGGAATTGACGGGGGCCCGCACAAGCAGCGGAGCGTG 893
KB1-VC          ACGGTCGCAAGGCTAAAACTCAAAGGAATTGACGGGGGCCCGCACAAGCAGCGGAGCGTG 890
KB1-PCE         ACGGTCGCAAGGCTAAAACTCAAAGGAATTGACGGGGGCCCGCACAAGCAGCGGAGCGTG 889
                **** **** ******* *********** ********************************

EW70-01#8       TGGTTTAATTCGATGCTACACGAAGAACCCTACCAAGATTTGACATGCATGGAGTAGTGA 952
Shaw16s#1       TGGTTTAATTCGATGCTACACGAAGAACCTTACCAAGATTTGACATGCATGAAGTAGTGA 956
BCI#1           TGGTTTAATTCGATGCTACACGAAGAACCTTACCAAGATTTGACATGCATGAAGTAGTGA 955
BCI#16          TGGTTTAATTCGATGCTACACGAAGAACCTTACCAAGATTTGACATGCATGAAGTAGTGA 953
EW70-01#6       TGGTTTAATTCGATGCTACACGAAGAACCTTACTAAGATTTGACATGCATGAAGTAGTGA 953
EW70-01#3       TGGTTTAATTCGATGCTACACGAAGAGCCTTACCAAGATTTGACATGCATGAAGTAGTGA 955
BCI#17          TGGTTTAATTCGATGCTACACGAAGAACCTTACCAAGATTCGACATGCATGAAGTAGTGA 954
Shaw16s#2       TGGTTTAATTCGATGCTACACGAAGAACCTTACCAAGATTTGACATGCATGAAGTAGTGA 955
EW70-01#7       TGGTTTAATTCGATGCTACACAAAGAACCTTACCAAGATTTGACATGCATGAAGTAGTGA 955
Shaw16s#3       TGGTTTAATTCGATGCTACACGAAGAACCTTACCAAGATTTGACATGCATGAAGTAGTGA 955
BCI#15          TGGTTTAATTCGATGCTACACGAAGAAMCTTACCAAGATTTGACATGCATGAAGTAGTGA 955
EW70-01#2       TGGTTTAATTCGATGCTACACGAAGAACCTTACCAAGATTTGACATGCATGAAGTAGTGA 955
Shaw16s#4       TGGTTTAATTCGATGCTACACGAAGAACCTTACCTAGATTTGACATGCATGAAGTAGTGA 899
BCI#3           TGGTTTAATTCGATGCTACACGAAGAACCTTACCAAGATTTGACATGCATGAAGTAGTGA 953
KB1-VC          TGGTTTAATTCGATGCTACACGAAGAACCTTACCAAGATTTGACATGCATGTAGTAGTGA 950
KB1-PCE         TGGTTTAATTCGATGCTACACGAAGAACCTTACCAAGATTTGACATGCATGTAGTAGTGA 949
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EW70-01#8       ACCGAAAGGGAAACGACCTGTTAAGTCAGGAGTTTGCACAGGTGCTGCATGGCTGTCGTC 1012
Shaw16s#1       ACCGAAAGGGAAACGACCTGTTAAGTCAGGAGTTTGCACAGGTGCTGCATGGCTGTCGTC 1016
BCI#1           ACCGAAAGGGAAACGACCTGTTAAGTCAGGAGTTTGCACAGGTGCTGCATGGCTGTCGTC 1015
BCI#16          ACCGAAAGGGAAACGACCTGTTAAGTCAGGAGTTTGCACAGGTGCTGCATGGCTGTCGTC 1013
EW70-01#6       ACCGAAAGGGAAACGACCTGTTAAGTCAGGAGTTTGCACAGGTGCTGCATGGCTGTCGTC 1013
EW70-01#3       ACCGAAAGGGAAACGACCTGTTAAGTCAGGAGTTTGCACAGGTGCTGCATGGCTGTCGTC 1015
BCI#17          ACCGAAAGGGAAACGACCTGTTAAGTCAGGAGTTTGCACAGGTGCTGCATGGCTGTCGTC 1014
Shaw16s#2       ACCGAAAGGGAAACGACCTGTTAAGTCAGGAGTTTGCACAGGTGCTGCATGGCTGTCGTC 1015
EW70-01#7       ACCGAAAGGGAAACGACCTGTTAAGTCAGGAGTTTGCACAGGTGCTGCATGGCTGTCGTC 1015
Shaw16s#3       ACCGAAAGGGAGACGACCTGTTAAGTCAGGAGTTTGCACAGGTGCTGCATGGCTGTCGTC 1015
BCI#15          ACCGAAAGGGAAACGATCTGTTAAGTCAGGAGTTTGCACAGGTGCTGCATGGCTGTCGTC 1015
EW70-01#2       ACCGAAAGGGAAACGACCTGTTAAGTCAGGAGTTTGCACAGGTGCTGCATGGCTGTCGTC 1015
Shaw16s#4       ACCGAAAGGGAAACGACCTGTTAAGTCAGGAGTTTGCACAGGTGCTGCATGGCTGTCGTC 959
BCI#3           ACCGAAAGGGAAACGACCTGTTAAGTCAGGAGTTTGCACAGGTGCTGCATGGCTGTCGTC 1013
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KB1-VC          ACTGAAAGGGGAACGACCTGTTAAGTCAGGAACTTGCACAGGTGCTGCATGGCTGTCGTC 1010
KB1-PCE         ACTGAAAGGGGAACGACCTGTTAAGTCAGGAACTTGCACAGGTGCTGCATGGCTGTCGTC 1009
                ** ******* **** ************** ****************************

EW70-01#8       AGCTCGTGCCGTGAGGTGTTTGG-TTAAGTCCTGCAACGAGCGCAACCC-TTGTTGCTAG 1070
Shaw16s#1       AGCTCGTGCCGTGAGGTGTTTGG-TTAAGTCCTGCAACGAGCGCAACCC-TTGTTGCTAG 1074
BCI#1           AGCTCGTGCCGTGAGGTGTTTGG-TTAAGTCCTGCAACGAGCGCAACCC-TTGTTGCTAG 1073
BCI#16          AGCTCGTGCCGTGAGGTGTTTGGGTTAAGTCCTGCAACGAGCGCAACCCCTTGTTGCTAG 1073
EW70-01#6       AGCTCGTGCCGTGAGGTGTTTGG-TTAAGTCCTGCAACGAGCGCAACCC-TTGTTGCTAG 1071
EW70-01#3       AGCTCGTGCCGTGAGGTGTTTGG-TTAAGTCCTGCAACGAGCGCAACCC-TTGTTGCTAG 1073
BCI#17          AGCTCGTGCCGTGAGGTGTTTGG-TTAAGTCCTGCAACGAGCGCAACCC-TTGTTGCTAG 1072
Shaw16s#2       AGCTCGTGCCGTGAGGTGTTTGG-TTAAGTCCTGCAACGAGCGCAACCC-TTGTTGCTAG 1073
EW70-01#7       AGCTCGTGCCGTGAGGTGTTTGG-TTAAGTCCTGCAACGAGCGCAACCC-TTGTTGCTAG 1073
Shaw16s#3       AGCTCGTGCCGTGAGGTGTTTGG-TTAAGTCCTGCAACGAGCGCAACCC-TTGTTGCTAG 1073
BCI#15          AGCTCGTGCCGTGAGGTGTTTGG-TTAAGTCCTGCAACGAGCGCAACCC-TTGTTGCTAG 1073
EW70-01#2       AGCTCGTGCCGTGAGGTGTTTGG-TTAAGTCCTGCAACGAGCGCAACCC-TTGTTGCTAG 1073
Shaw16s#4       AGCTCGTGCCGTGAGGTGTTTGG-TTAAGTCCTGCAACGAGCGCAACCC-TTGTTGCTAG 1017
BCI#3           AGCTCGTGCCGTGAGGTGTTTGG-TTAAGTCCTGCAACGAGCGCAACCC-TTGTTGCTAG 1071
KB1-VC          AGCTCGTGCCGTGAGGTGTTTGG-TTAAGTCCTGCAACGAGCGCAACCC-TTGTTGCTAG 1068
KB1-PCE         AGCTCGTGCCGTGAGGTGTTTGG-TTAAGTCCTGCAACGAGCGCAACCC-TTGTTGCTAG 1067
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EW70-01#8       TTAAATTTTCTAGCGAGACTGCCCCGCGAAACGGGGAGGAAGGTGGGGATGACATCAAGT 1130
Shaw16s#1       TTAAATTTTCTAGCGAGACTGCCCCGCGAAACGGGGAGGAAGGTGGGGATGACGTCAAGT 1134
BCI#1           TTAAATTTTCTAGCGAGACCGCCCCGCGAAACGGGGAGGAAGGTGGGGATGACGTCAAGT 1133
BCI#16          TTAAATTTTCTAGCGAGACTGCCCCGCGAAACGGGGAGGAAGGTGGGGATGACGTCAAGT 1133
EW70-01#6       TTAAATTTTCTAGCGAGACTGCCCCGCGAAACGGGGAGGAAGGTGGGGATGACGTCAAGT 1131
EW70-01#3       TTAAATTTTCTAGCGAGACTGCCCCGCGAAACGGGGAGGAAGGTGGGGATGACGTCAAGT 1133
BCI#17          TTAAATTTTCTAGCGAGACTGCCCCGCGAAACGGGGAGGAAGGTGGGGATGACGTCAAGT 1132
Shaw16s#2       TTAAATTTTCTAGCGAGACTGCCCCGCGAAACGGGGAGGAAGGTGGGGATGACGTCAAGT 1133
EW70-01#7       TTAAATTTTCTAGCGAGACTGCCCCGCGAAACGGGGAGGAAGGTGGGGATGACGTCAAGT 1133
Shaw16s#3       TTAAATTTTCTAGCGAGACTGCCCCGCGAAACGGGGAGGAAGGTGGGGATGACGTCAAGT 1133
BCI#15          TTAAATTTTCTAGCGAGACTGCCCCGCGAAACGGGGAGGAAGGTGGGGATGACGTCAAGT 1133
EW70-01#2       TTAAATTTTCTAGCGAGACTGCCCCGCGAAACGGGGAGGAAGGTGGGGATGACGTCAAGT 1133
Shaw16s#4       TTAAATTTTCTAGCGAGACTGCCCCGCGAAACGGGGAGGAAGGTGGGGATGACGTCAAGT 1077
BCI#3           TTAAATTTTCTAGCGAGACTGCCCCGCGAAACGGGGAGGAAGGTGGGGATGACGTCGAGT 1131
KB1-VC          TTAAATTTTCTAGCGAGACTGCCCCGCGAAACGGGGAGGAAGGTGGGGATGACGTCAAGT 1128
KB1-PCE         TTAAATTTTCTAGCGAGACTGCCCCGCGAAACGGGGAGGAAGGTGGGGATGACGTCAAGT 1127
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EW70-01#8         CAGCATGGCCTTTATATCTTGGGCTACACACACGCTACAATGGACAGAACAATAGGTTGC 1190
Shaw16s#1         CAGCATGGCCTTTATATCTTGGGCTACACACACGCTACAATGGACAGAACAATAGGTTGC 1194
BCI#1             CAGCATGGCCTTTATATCTTGGGCTACACACACGCTACAATGGACAGAACAATAGGTTGC 1193
BCI#16            CAGCATGGCCTTTATATCCTGGGCTACACACACGCTACAATGGACAGAACAATAGGTTGC 1193
EW70-01#6         CAGCATGGCCTTTATATCTTGGGCTACACACACGCTACAATGGACAGAACAATAGGTTGC 1191
EW70-01#3         CAGCATGGCCTTTATATCTTGGGCTACACACACGCTACAATGGACAGAACAATAGGTTGC 1193
BCI#17            CAGCATGGCCTTTATATCTTGGGCTACACACACGCTACAATGGACAGAACAATAGGTTGC 1192
Shaw16s#2         CAGCATGGCCTTTATATCTTGGGCTACACACACGCTACAATGGACAGAACAATAGGTTGC 1193
EW70-01#7         CAGCATGGCCTTTATATCTTGGGCTACACACACGCTACAATGGACAGAACAATAGGTTGC 1193
Shaw16s#3         CAGCATGGCCTTTATATCTTGGGCTACACACACGCTACAATGGACAGAACAATAGGTTGC 1193
BCI#15            CAGCATGGCCTTTATATCTTGGGCTACACACACGCTACAATGGACAGAACAATAGGTTGC 1193
EW70-01#2         CAGCATGGCCTTTATATCTTGGGCTACACACACGCTACAATGGACAGAGCAATAGGTTGC 1193
Shaw16s#4         CAGCATGGCCTTTATATCTTGGGCCACACACACGCTACAATGGACAGAACAATAGGTTGC 1137
BCI#3             CAGCATGGCCTTTATATCTTGGGCTACACACACGCTACAATGGACAGAACAGTAGGTTGC 1191
KB1-VC            CAGCATGGCCTTTATATCTTGGGCTACACACACGCTACAATGGACAGAACAATAGGTTGC 1188
KB1-PCE           CAGCATGGCCTTTATATCTTGGGCTACACACACGCTACAATGGACAGAACAATAGGTTGC 1187
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EW70-01#8         AACAGTGTGAACTGGAGCTAATCCCCAAAGCTGTCCTCAGTTCGGATTGCAGGCTGAAAC 1250
Shaw16s#1         AACAGTGTGAACTGGAGCTAATCCCCAAAGCTGTCCTCAGTTCGGATTGCAGGCTGAAAC 1254
BCI#1             AACAGTGTGAACTGGAGCTAATCCCCAAAGCTGTCCTCAGTTCGGATTGCAGGCTGAAAC 1253
BCI#16            AACAGTGTGAACTGGAGCTAATCCCCAAAGCTGTCCTCAGTTCGGATTGCAGGCTGAAAC 1253
EW70-01#6         AACAGTGTGAACTGGAGCTAATCCCCAAAGCTGTCCTCAGTTCGGATTGCAGGCTGAAAC 1251
EW70-01#3         AACAGTGTGAACTGGAGCTAATCCCCAAAGCTGTCCTCAGTTCGGATTGCAGGCTGAAAC 1253
BCI#17            AACAGTGTGAACTGGAGCTAATCCCCAAAGCTGTCCTCAGTTCGGATTGCAGGCTGAAAC 1252
Shaw16s#2         AACAGTGTGAACTGGAGCTAATCCCCAAAGCTGTCCTCAGTTCGGATTGCAGGCTGAAAC 1253
EW70-01#7         AACAGTGTGAACTGGAGCTAATCCCCAAAGCTGTCCTCAGTTCGGATTGCAGGCTGAAAC 1253
Shaw16s#3         AACAGTGTGAACTGGAGCTAATCCCCAAAGCTGTCCTCAGTTCGGATTGCAGGCTGAAAC 1253
BCI#15            AACAGTGTGAACTGGAGCTAATCCCCAAAGCTGTCCTCAGTTCGGATTGCAGGCTGAAAC 1253
EW70-01#2         AACAGTGTGAACTGGAGCTAATCCCCAAAGCTGTCCTCAGTTCGGATTGCAGGCTGAAAC 1253
Shaw16s#4         AACAGTGTGAACTGGAGCTAATCCCCAAAGCGGTCCTCAGTTCGGATTGCAGGCTGAAAC 1197
BCI#3             AACAGTGTGAACTGGAGCTAATCCCCAAAGCTGTCCTCAGTTCGGATTGCAGGCTGAAAC 1251
KB1-VC            AACAGTGCGAACTGGAGCTAATCCCCAAAGCTGTCCTCAGTTCGGATTGCAGGCTGAAAC 1248
KB1-PCE           AACAGTGCGAACTGGAGCTAATCCCCAAAGCTGTCCTCAGTTCGGATTGCAGGCTGAAAC 1247
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EW70-01#8       CCGCCTGCATGAAGTTGGAGTTGCTAGTATCAGGATATCAGCAAGGTGCGGTGAATACGT 1310
Shaw16s#1       CCGCCTGCATGAAGTTGGAGTTGCTAGTAACCGCATATCAGCAAGGTGCGGTGAATACGT 1314
BCI#1           CCGCCTGCATGAAGTTGGAGTTGCTAGTAACCGCATATCAGCAAGGTGCGGTGAATACGT 1313
BCI#16          CCGCCTGCATGAAGTTGGAGTTGCTAGTAACCGCATATCAGCAAGGTGCGGTGAATACGT 1313
EW70-01#6       CCGCCTGCATGAAGTTGGAGTTGCTAGTAACCGCATATCAGCAAGGTGCGGTGAATACGT 1311
EW70-01#3       CCGCCTGCATGAAGTTGGAGTTGCTAGTAACCGCATATCAGCAAGGTGCGGTGAATACGT 1313
BCI#17          CCGCCTGCATGAAGTTGGAGTTGCTAGTAACCGCATATCAGCAAGGTGCGGTGAATACGT 1312
Shaw16s#2       CCGCCTGCATGAAGTTGGAGTTGCTAGTAACCGCATATCAGCAAGGTGCGGTGAATACGT 1313
EW70-01#7       CCGCCTGCATGAAGTTGGAGTTGCTAGTAACCGCATATCAGCAAGGTGCGGTGAATACGT 1313
Shaw16s#3       CCGCCTGCATGAAGTTGGAGTTGCTAGTAACCGCATATCAGCAAGGTGCGGTGAATACGT 1313
BCI#15          CCGCCTGCATGAAGTTGGAGTTGCTAGTAACCGCATATCAGCAAGGTGCGGTGAATACGT 1313
EW70-01#2       CCGCCTGCATGAAGTTGGAGTTGCTAGTAACCGCATATCAGCAAGGTGCGGTGAATACGT 1313
Shaw16s#4       CCGCCTGCATGAAGTTGGAGTTGCTAGTAACCGCATATCAGCAAGGTGCGGTGAATACGT 1257
BCI#3           CCGCCTGCATGAAGTTGGAGTTGCTAGTAACCGCATATCAGCAAGGTGCGGTGAATACGT 1311
KB1-VC          CCGCCTGCATGAAGTTGGAGTTGCTAGTAACCGCATATCAGCATGGTGCGGTGAATACGT 1308
KB1-PCE         CCGCCTGCATGAAGTTGGAGTTGCTAGTAACCGCATATCAGCATGGTGCGGTGAATACGT 1307
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EW70-01#8       TCTCGGGCCTTG-ACACACCGCCCGTCACGTCATGAAAGCCGGTAACACTTGAAGTCGAT 1369
Shaw16s#1       TCTCGGGCCTTG-ACACACCGCCCGTCACGTCATGAAAGCCGGTAACACTTGAAGTCGAT 1373
BCI#1           TCTCGGGCCTTGTACACACCGCCCGTCACGTCATGAAAGCCGGTAACACTTGAAGTCGAT 1373
BCI#16          TCTCGGGCCTTGTACACACCGCCCGTCACGTCATGAAAGCCGGTAACACTTGAAGTCGAT 1373
EW70-01#6       TCTCGGGCCT-GTACACACCGCCCGTCACGTCATGAAAGCCGGTAACACTTGAAGTCGAT 1370
EW70-01#3       TCTCGGGCCTTGTACACACCGCCCGTCACGTCATGAAAGCCGGTAACACTTGAAGTCGAT 1373
BCI#17          TCTCGGGCCT-GTACACACCGCCCGTCACGTCATGAAAGCCGGTAACACTTGAAGTCGAT 1371
Shaw16s#2       TCTCGGGCCT-GTACACACCGCCCGTCACGTCATGAAAGCCGGTAACACTTGAAGTCGAT 1372
EW70-01#7       TCTCGGGCCT-GTACACACCGCCCGTCACGTCATGAAAGCCGGTAACACTTGAAGTCGAT 1372
Shaw16s#3       TCTCGGGCCTTGTACACACCGCCCGTCACGTCATGAAAGCCGGTAACACTTGAAGTCGAT 1373
BCI#15          TCTCGGGCCTTGTACACACCGCC---------------------------------- 1336
EW70-01#2       TCTCGGGCCTTGTACACACCGCCCGTCACGTCATGAAAGCCGGTAACACTTGAAGTCGAT 1373
Shaw16s#4       TCTCGGGCCTTG-ACACACCGCC---------------------------------- 1279
BCI#3           TCTCGGGCCTTGTACACACCGCCCGTCACGTCATGAAAGCCGGTAACACTTGAAGTCGAT 1371
KB1-VC          TCTCGGGCCTTGTACACACCGCCCGTCACGTCATGAAAGCCGGTAACACTTGAAGTCGAT 1368
KB1-PCE         TCTCGGGCCTTGTACACACCGCCCGTCACGTCATGAAAGCCGGTAACACTTGAAGTCGAT 1367
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EW70-01#8       GTGC-------------- 1373
Shaw16s#1       GTGCCAACC-AAGGG--- 1387
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BCI#1           GTGCCAACC-AAGGGC-- 1388
BCI#16          GTGCCAACC-AAGGGC-- 1388
EW70-01#6       GTGCCAACC-AAGGGC-- 1385
EW70-01#3       GTGCCAACC-AAGGGC-- 1388
BCI#17          GTGCCAACC-AAGGGC-- 1386
Shaw16s#2       GTGCCAACCCAAGGGC-- 1388
EW70-01#7       GTGCCAACC-AAGGGC-- 1387
Shaw16s#3       GTGCCAACC-AAGGGC-- 1388
BCI#15          ------------------
EW70-01#2       GTGCCAACC-AAGGGC-- 1388
Shaw16s#4       ------------------
BCI#3           GTGCCAACC-AAGGGC-- 1386
KB1-VC          GTGCCAACCGCAAGGAGG 1386
KB1-P
```

***vcrA* Gene analysis.** Quantitative PCR analysis suggested that the functional reductase gene *vcrA* was not detected within the Seal Beach site 70 environmental sample, but was present in high concentrations in all three bioaugmentation cultures. Therefore, this reductase gene was identified as the preliminary target for tracking the growth and transport of the bioaugmentation culture in the field. In order to determine if there are significant differences between the *vcrA* gene sequences present within the bioaugmentation cultures, clone libraries were constructed using *vcrA*-specific PCR primers. First, PCR was performed using *vcrA* primers identified in Table 1 to generate an approximately 1,400 bp PCR product of the vcrA gene in the Seal Beach Site 70 sample EW70-01, and bioaugmentation cultures Shaw and BCI. The Seal Beach Site 70 sample did not amplify, confirming that the *vcrA* gene was not detected using either the QPCR or PCR protocols described. The BCI bioaugmentation culture, however, did not amplify either. Therefore, while QPCR analysis identified high gene copy numbers of *vcrA* within this culture, the long primer set used for the clone library construction did not amplify, and therefore a clone library could not be constructed.

A clone library targeting *vcrA* was generated using the Shaw bioaugmentation culture, and four clones were sequenced. The approximately 1400 bp DNA sequence obtained from each clone was initially aligned against known sequences using the BLAST tool (Table 4) in order to determine the closest match with sequences in the GenBank database. In addition to the sequences obtained from the library, an alignment was generated using a ClustalW algorithm (http://www.ebi.ac.uk/clustalw/) with published sequence for vcrAKB1RdhAB14 *vcrA* from bioaugmentation culture KB-1, and from *Dehalococcoides* strain VS (Table 4 and Figure 2). The GenBank alignment suggested that all four Shaw vcrA sequences most closely matched the *vcrA* gene published for *Dehalococcoides* strain VS with greater than 99% sequence similarity (Table 4).

Figure 2 illustrates the DNA sequence alignment for the Shaw *vcrA* clone sequences, and the *vcrA* sequence from *Dehalococcoides* strain VS and the KB-1 *vcrA* published sequence. All of the sequences evaluated were highly similar, with little distinction between the different strains. These data will be archived and evaluated further should indigenous strains of *vcrA* be detected in the field at Seal Beach following biostimulation, but before bioaugmentation.

Table 4. Genebank results for the reductase gene *vcrA* clone library results for the Shaw bioaugmentation culture.

Clone	target	Closest GenBank match	% similarity	Citation
Shaw vcrA #2	vcrA	Bacterium VS vinyl-chloride reductive dehalogenase operon AY322364.1|	1433/1442 (99%)	Muller, et al 2004 AEM. 70 (8), 4880-4888
Shaw vcrA #5	vcrA	Bacterium VS vinyl-chloride reductive dehalogenase operon AY322364.1|	1384/1393 (99%),	Muller, et al 2004 AEM. 70 (8), 4880-4888

Shaw vcrA #1	vcrA	Bacterium VS vinyl-chloride reductive dehalogenase operon AY322364.1|	1381/1391 (99%)	Muller, et al 2004 AEM. 70 (8), 4880-4888
Shaw vcrA #3	vcrA	Bacterium VS vinyl-chloride reductive dehalogenase operon AY322364.1|	1375/1381 (99%)	Muller, et al 2004 AEM. 70 (8), 4880-4888

Figure 2. Sequence alignment from Shaw and KB1 vcrA sequences and Strain VS.

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ShawvcrA#3              ----------------CTTCAGATGAGAATGTCAGGTGAAGAGCAAAAGAAGCGAATTTT 44
ShawvcrA#5              ------------------TCAGATGAGAATGTCAGGTGAAGAGCAAAAGAAGCGAATTTT 42
ShawvcrA#1              ----------------CTTCAGATGAGAATGTCAGGTGAAGAGCAAAAGAAGCGAATTTT 44
ShawvcrA#2              -------GGGCATAGGCTTCAGATGAGAATGTCAGGTGAAGAGCAAAAGAAGCGAATTTT 53
OperonfromStrainVS      ATCATGGGGCAATAGGCTTCAGGTGAGAATGTCAGGTGAAGAGCAAAAGAAGCGAATTTT 960
vcrAKB1RdhAB14          ATCATGGGGCAATAGGCTTCAGATGAGAATGTCAGGTGAAGAGCAAAAGAAGCGAATTTT 292
                                      **** **************************************

ShawvcrA#3              GGCCGCTAAAAAAGAGAGKTTCCCTGGTTGGGACGGTGGGTTACACGGGAGAGGGGATCA 104
ShawvcrA#5              GGCCGCCAAAAAAGAGAGGTTCCCTGGTTGGGACGGTGGGTTACACGGGAGAGGGGATCA 102
ShawvcrA#1              GGCCGCTAAAAAAGAGAGGTTCCCTGGTTGGGACGGTGGGTTACACGGGAGAGGGGATCA 104
ShawvcrA#2              GGCCGCTAAAAAAGAGAGGTTCCCTGGTTGGGACGGTGGGTTACACGGGAGAGGGGATCA 113
OperonfromStrainVS      GGCCGCTAAAAAAGAGAGGTTCCCTGGTTGGGACGGTGGGTTACACGGGAGAGGGGATCA 1020
vcrAKB1RdhAB14          GGCCGCTAAAAAAGAGAGGTTCCCTGGTTGGGACGGTGGGTTACACGGGAGAGGGGATCA 352
                        ****** ********** ****************************************

ShawvcrA#3              GCGGGCGGATGCACTATTTTACGCAGTAACTCAACCATTTCCTGGTAGTGGTGAGGAAGG 164
ShawvcrA#5              GCGGGCGGATGCACTATTTTACGCAGTAACTCAACCATTTCCTGGTAGTGGTGAGGAAGG 162
ShawvcrA#1              GCGGGCGGATGCACTATTTTACGCAGTAACTCAGCCACTTCCTGGTAGTGGTGAGGAAGG 164
ShawvcrA#2              GCGGGCGGATGCACTATTTTACGCAGTAACTCAACCATTTCCTGGTAGTGGTGAGGAAGG 173
OperonfromStrainVS      GCGGGCGGATGCACTATTTTACGCAGTAACTCAACCATTTCCTGGTAGTGGTGAGGAAGG 1080
vcrAKB1RdhAB14          GCGGGCGGATGCACTATTTTACGCAGTAACTCAACCATTTCCTGGTAGTGGTGAGGAAGG 412
                        ********************************** *** ***********************

ShawvcrA#3              GCACGGACTATTCCAACCTTATCCTGATCAACCCGGTAAGTTTTACGCGAGATGGGGTTT 224
ShawvcrA#5              GCACGGACTATTCCAACCTTATCCTGATCAACCCGGTAAGTTTTACGCGAGATGGGGTTT 222
ShawvcrA#1              GCACGGACTATTCCAACCTTATCCTGATCAACCCGGTAAGTTTTACGCGAGATGGGGTTT 224
ShawvcrA#2              GCGCGGACTATTCCAACCTTATCCTGATCAACCCGGTAAGTTTTACGCGAGATGGGGTTT 233
OperonfromStrainVS      GCACGGACTATTCCAACCTTATCCTGATCAACCCGGTAAGTTTTACGCGAGATGGGGTTT 1140
vcrAKB1RdhAB14          GCACGGACTATTCCAACCTTATCCTGATCAACCCGGTAAGTTTTACGCGAGATGGGGTTT 472
                        ** ************************************************************

ShawvcrA#3              GTATGGTCCGCCACATGATTCAGCGCCACCTGATGGGAGCGTACCAAAATGGGAGGGTAC 284
ShawvcrA#5              GTATGGTCCGCCACGTGATTCAGCGCCACCTGATGGGAGCGTACCAAAATGGGAGGGTAC 282
ShawvcrA#1              GTATGGTCCGCCACATGATTCAGCGCCACCTGATGGGAGCGTACCAAAATGGGAGGGTAC 284
ShawvcrA#2              GTATGGTCCGCCACATGATTCAGCGCCACCTGATGGGAGCGTACCAAAATGGGAGGGTAC 293
OperonfromStrainVS      GTATGGTCCGCCACATGATTCAGCGCCACCTGATGGGAGCGTACCAAAATGGGAGGGTAC 1200
vcrAKB1RdhAB14          GTATGGTCCGCCACATGATTCAGCGCCACCTGATGGGAGCGTACCAAAATGGGAGGGTAC 532
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ShawvcrA#3              TCCAGAAGACAATTTTCTAATGCTGAGGGCAGCTGCAAAATATTTTGGTGCTGGTGGCGT 344
ShawvcrA#5              TCCAGAAGACAATTTTCTAATGCTGAGGGCAGCTGCAAAATATTTTGGTGCTGGTGGCGT 342
ShawvcrA#1              TCCAGAAGACAATTTTCTAATGCTGAGGGCAGCTGCAAAATATTTTGGTGCTGGTGGCGT 344
ShawvcrA#2              TCCAGAAGACAATTTTCTAATGCTGAGGGCAGCTGCAAAATATTTTGGTGCTGGTGGCGT 353
OperonfromStrainVS      TCCAGAAGACAATTTTCTAATGCTGAGGGCAGCTGCAAAATATTTTGGTGCTGGTGGCGT 1260
vcrAKB1RdhAB14          TCCAGAAGACAATTTTCTAATGCTGAGGGCAGCTGCAAAATATTTTGGTGCTGGTGGCGT 592
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ShawvcrA#3              TGGTGCTCTTAACCTGGCAGATCCCAAATGCAAAAAACTAATATATAAGAAAGCTCAGCC 404
ShawvcrA#5              TGGTGCTCTTAACCTGGCAGATCCCAAATGCAAAAAACTAATATATAAGAAAGCTCAGCC 402
ShawvcrA#1              TGGTGCTCTTAACCTGGCAGATCCCAAATGCAAAAAACTAATATATAAGAAAGCTCAGCC 404
ShawvcrA#2              TGGTGCTCTTAACCTGGCAGATCCCAAATGCAAAAAACTAATATATAAGAAAGCTCAGCC 413
OperonfromStrainVS      TGGTGCTCTTAACCTGGCAGATCCCAAATGCAAAAAACTAATATATAAGAAAGCTCAGCC 1320
vcrAKB1RdhAB14          TGGTGCTCTTAACCTGGCAGATCCCAAATGCAAAAAACTAATATATAAGAAAGCTCAGCC 652
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ShawvcrA#1              GATGACTCTAGGAAAAGGAACATACAGTGAAATAGGTGGACCAGGAATGATCGATACAAA 464
ShawvcrA#2              GATGACTCTAGGAAAAGGAACATACAGTGAAATAGGTGGACCAGGAATGATCGATGCAAA 473
OperonfromStrainVS      GATGACTCTAGGAAAAGGAACATACAGTGAAATAGGTGGACCAGGAATGATCGATGCAAA 1380
vcrAKB1RdhAB14          GATGACTCTAGGAAAAGGAACATACAGTGAAATAGGTGGACCAGGAATGATCGATGCAAA 712
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ShawvcrA#5              ATTTTATCCCAAGGTTCCTGACCATGCCGTACCTATTAACTTTAAGGAAGCGGATTATAG 522
ShawvcrA#1              ATTTTATCCCAAGGTTCCTGACCATGCCGTACCTATTAACTTTAAGGAAGCGGATTATAG 524
ShawvcrA#2              ATTTTATCCCAAGGTTCCTGACCATGCCGTACCTATTAACTTTAAGGAAGCGGATTATAG 533
OperonfromStrainVS      AATTTATCCCAAGGTTCCTGACCATGCCGTACCTATTAACTTTAAGGAAGCGGATTATAG 1440
vcrAKB1RdhAB14          ATTTTATCCCAAGGTTCCTGACCATGCCGTACCTATTAACTTTAAGGAAGCGGATTATAG 772
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ShawvcrA#3              CTACTACAATGATGCAGAGTGGGTTATTCCAACAAAGTGTGAATCCATTTTCACTTTCAC 584
ShawvcrA#5              CTACTACAATGATGCAGAGTGGGTTATTCCAACAAAGTGTGAATCCATTTTCACTTTCAC 582
ShawvcrA#1              CTACTACAATGATGCAGAGTGGGTTATTCCAACAAAGTGTGAATCCATTTTCACTTTCAC 584
ShawvcrA#2              CTACTACAATGATGCAGAGTGGGTTATTCCAACAAAGTGTGAATCCATTTTCACTTTCAC 593
OperonfromStrainVS      CTACTACAATGATGCAGAGTGGGTTATTCCAACAAAGTGTGAATCCATTTTCACTTTCAC 1500
vcrAKB1RdhAB14          CTACTACAATGATGCAGAGTGGGTTATTCCAACAAAGTGTGAATCCATTTTCACTTTCAC 832
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ShawvcrA#3              CCTACCTCAACCACAAGAACTCAATAAGAGGACGGGTGGTATAGCAGGTGCTGGATCATA 644
ShawvcrA#5              CCTACCTCAACCACAAGAACTCAATAAGAGGACGGGTGGTATAGCAGGTGCTGGATCATA 642
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ShawvcrA#1              CCTACCTCAACCACAAGAACTCAATAAGAGGACGGGTGGTATAGCAGGTGCTGGATCATA 644
ShawvcrA#2              CCTACCTCAACCACAAGAACTCAATAAGAGGACGGGTGGTATAGCAGGTGCTGGATCATA 653
OperonfromStrainVS      CCTACCTCAACCACAAGAACTCAATAAGAGGACGGGTGGTATAGCAGGTGCTGGATCATA 1560
vcrAKB1RdhAB14          CCTACCTCAACCACAAGAACTCAATAAGAGGACGGGTGGTATAGCAGGTGCTGGATCATA 892
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ShawvcrA#3              TACTGTATACAAAGATTTCGCTAGGGTAGGCACTTTAGTCCAAATGTTTATTAAGAATCT 704
ShawvcrA#5              TACTGTATACAAAGATTTCGCTAGGGTAGGCACTTTAGTCCAAATGTTTATTAAGAATCT 702
ShawvcrA#1              TACTGTATACAAAGATTTCGCTAGGGTAGGCACTTTAGTCCAAATGTTTATTAAGAATCT 704
ShawvcrA#2              TACTGTATACAAAGATTTCGCTAGGGTAGGCACTTTAGTCCAAATGTTTATTAAGAATCT 713
OperonfromStrainVS      TACTGTATACAAAGATTTCGCTAGGGTAGGCACTTTAGTCCAAATGTTTATTAAGTATCT 1620
vcrAKB1RdhAB14          TACTGTATACAAAGATTTCGCTAGGGTAGGCACTTTAGTCCAAATGTTTATTAAGAATCT 952
                        ************************************************** ****

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ShawvcrA#5              AGGTTATCACGCTTTATATTGGCCAATTGGATGGGGACCGGGTGGTTGCTTTACCACTTT 762
ShawvcrA#1              AGGTTATCACGCTTTATATTGGCCAATTGGATGGGGACCGGGTGGTTGCTTTACCACTTT 764
ShawvcrA#2              AGGTTATCACGCTTTATATTGGCCAATTGGACGGGGACCGGGTGGTTGCTTTACCACTTT 773
OperonfromStrainVS      AGGTTATCACGCTTTATATTGGCCAATTGGATGGGGACCGGGTGGTTGCTTTACCACTTT 1680
vcrAKB1RdhAB14          AGGTTATCACGCTTTATATTGGCCAATTGGATGGGGACCGGGTGGTTGCTTTACCACTTT 1012
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ShawvcrA#3              TGACGGGCAAGGTGAACAGGGTAGAACAGGTGCTGCTATCCATTGGAAGTTTGGTTCTTC 824
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ShawvcrA#1              TGACGGGCAAGGTGAACAGGGTAGAACAGGTGCTGCTATCCATTGGAAGTTTGGTTCTTC 824
ShawvcrA#2              TGACGGGCAAGGTGAACAGGGTAGAACAGGTGCTGCTATCCATTGGAAGTTTGGTTCTTC 833
OperonfromStrainVS      TGACGGGCAAGGTGAACAGGGTAGAACAGGTGCTGCTATCCATTGGAAGTTTGGTTCTTC 1740
vcrAKB1RdhAB14          TGACGGGCAAGGTGAACAGGGTAGAACAGGTGCTGCTATCCATTGGAAGTTTGGTTCTTC 1072
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ShawvcrA#3              ACAACGTGGTTCTGAAAGAGTAGTAA-CTGATTTACCGATAGCTCCTACCCCGCCAATTG 883
ShawvcrA#5              ACAACGTGGTTCTGAAAGAGTAGTAA-CTGATTTACCGATAGCTCCTACCCCGCCAATTG 881
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ShawvcrA#2              ACAACGTGGTTCTGAAAGAGTAGTAAACTGATTTACCGATAGCTCCTACCCCGCCAATTG 893
OperonfromStrainVS      ACAACGTGGTTCTGAAAGAGTAATAA-CTGATTTACCGATAGCTCCTACCCCGCCAATTG 1799
vcrAKB1RdhAB14          ACAACGTGGTTCTGAAAGAGTAGTAA-CTGATTTACCGATAGCTCCTACCCCGCCAATTG 1131
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ShawvcrA#5              ATGCAGGTATGTTTTGAGTTTTGCMAAACCTGTCATATATGCCGTGACGTTTGCGTCTCT 941
ShawvcrA#1              ATGCAGGTATGTTT-GAGCTTTGCAAAACCTGTCATATATGCCGTGACGTTTGCGTCTCT 942
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OperonfromStrainVS      ATGCAGGTATGTTT-GAGTTTTGCAAAACCTGTTATATATGCCGTGACGTTTGCGTCTCT 1858
vcrAKB1RdhAB14          ATGCAGGTATGTTT-GAGTTTTGCAAAACCTGTTATATATGCCGTGACGTTTGCGTCTCT 1190
                        ************** *** ***** ******** *************************

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ShawvcrA#5              GGGGGTGTGCACCAAGAAGACGAACCAACTTGGGATTCAGGTAATTGGTGGAATGTACAA 1001
ShawvcrA#1              GGGGGTGTGCACCAAGAAGACGAACCAACTTGGGATTCAGGTAATTGGTGGAATGTACAA 1002
ShawvcrA#2              GGGGGTGTGCACCAAGAAGACGAACCAACTTGGGATTCAGGTAATTGGTGGAATGTACAA 1012
OperonfromStrainVS      GGGGGTGTGCACCAAGAAGACGAACCAACTTGGGATTCAGGTAATTGGTGGAATGTACAA 1918
vcrAKB1RdhAB14          GGGGGTGTGCACCAAGAAGACGAACCAACTTGGGATTCAGGTAATTGGTGGAATGTACAA 1250
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ShawvcrA#3              GGATATCTCGGCTACCGAACGGATTGGAGTGGTTGCCATAACCAGTGCGGTATGTGTCA- 1061
ShawvcrA#5              GGATATCTCGGCTACCGAACGGATTGGAGTGGTTGCCATAACCAGTGCGGTATGTGTCA- 1060
ShawvcrA#1              GGATATCTCGGCTACCGAACGGATTGGAGTGGTTGCCATAACCAGTGCGGTATGTGTCA- 1061
ShawvcrA#2              GGATATCTCGGCTACCGAACGGATTGGAGTGGTTGCCATAACCAGTGCGGTATGTGTCAC 1072
OperonfromStrainVS      GGATATCTCGGCTACCGAACGGATTGGAGTGGTTGCCATAACCAGTGCGGTATGTGTCA- 1977
vcrAKB1RdhAB14          GGATATCTCGGCTACCGAACGGATTGGAGTGGTTGCCATAACCAGTGCGGTATGTGTCA- 1309
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ShawvcrA#3              ATCCTCCTGCCCTTTTACTTATTTAGGTTTGGAAAATGCTTCATTAGTGCACAAAATAGT 1121
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ShawvcrA#1              ATCCTCCTGCCCTTTTACTTATTTAGGTTTGGAAAATGCTTCATTAGTGCACAAAATAGT 1121
ShawvcrA#2              ATCCTCCTGCCCTTTTACTTATTTAGGTTTGGAAAATGCTTCATTAGTGCACAAAATAGT 1132
OperonfromStrainVS      ATCCTCCTGCCCTTTTACTTATTTAGGTTTGGAAAATGCTTCATTAGTGCACAAAATAGT 2037
vcrAKB1RdhAB14          ATCCTCCTGCCCTTTTACTTATTTAGGTTTGGAAAATGCTTCATTAGTGCACAAAATAGT 1369
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ShawvcrA#3              AAAAGGTGTTGTTGCTAACACGACTGTTTTTAATAGTTTTTTTACCAATATGGAGAAAGC 1181
ShawvcrA#5              AAAAGGTGTTGTTGCTAACACGACTGTTTTTAATAGTTTTTTTACCAATATGGAGAAAGC 1180
ShawvcrA#1              AAAAGGTGTTGTTGCTAACACGACTGTTTTTAATAGTTTTTTTACCAATATGGAGAAAGC 1181
ShawvcrA#2              AAAAGGTGTTGTTGCTAACACGACTGTTTTTAATAGTTTTTTTACCAATATGGAGAAAGC 1192
OperonfromStrainVS      AAAAGGTGTTGTTGCTAACACGACTGTTTTTAATAGTTTTTTTACCAATATGGAGAAAGC 2097
vcrAKB1RdhAB14          AAAAGGTGTTGTTGCTAACACGACTGTTTTTAATAGTTTTTTTACCAATATGGAGAAAGC 1429
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ShawvcrA#3              ATTAGGATATGGTGATTTAACCATGGAAAATTCTAACTGGTGGAAAGAAGAAGGACCGAT 1241
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ShawvcrA#1              ATTAGGATATGGTGATTTAACCATGGAAAATTCTAACTGGTGGAAAGAAGAAGGACCGAT 1241
ShawvcrA#2              ATTAGGATATGGTGATTTAACCATGGAAAATTCTAACTGGTGGAAAGAAGAAGGACCGAT 1252
OperonfromStrainVS      ATTAGGATATGGTGATTTAACCATGGAAAATTCTAACTGGTGGAAAGAAGAAGGACCGAT 2157
vcrAKB1RdhAB14          ATTAGGATATGGTGATTTAACCATGGAAAATTCTAACTGGTGGAAAGAAGAAGGACCGAT 1489
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ShawvcrA#3              ATACGGCTTTGATCCCGGTACTTAGAAATAGATACTAAATTCGATAGAAAATAAAGGAAA 1301
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ShawvcrA#1              ATACGGCTTTGATCCCGGTACTTAGAAATAGATACTAAATTCGATAGAAAATAAAGGAAA 1301
ShawvcrA#2              ATACGGCTTTGATCCCGGTACTTAGAAATAGATACTAAATTCGATAGAAAATAAAGGAAA 1312
OperonfromStrainVS      ATACGGCTTTGATCCCGGTACTTAGAAATAGATACTAAATTCGATAGAAAATAAAGGAAA 2217
vcrAKB1RdhAB14          ATACGGCTTTGATCCCGGTACTTAG---------------------------------- 1514
                        *************************

ShawvcrA#3              TTGAAATGGATGCTATATATTTTTTCTTAACAATTGCATTAGCAGTTGGACTAACTATGC 1361
ShawvcrA#5              TTGAAATGGATGCTATATATTTTTTCTTAACAATTGCATTAGCAGTTGGACTAACTATGC 1360
ShawvcrA#1              TTGAAATGGATGCTATATATTTTTTCTTAACAATTGCAKTAGCAGTTGGACTAACTATGC 1361
ShawvcrA#2              TTGAAATGGATGCTATATATTTTTTCTTAACAATTGCATTAGCAGTTGGACTAACTATGC 1372
OperonfromStrainVS      TTGAAATGGATGCTATATATTTTTTCTTAACAATTGCATTAGCAGTTGGACTAACTATGC 2277
vcrAKB1RdhAB14          ------------------------------------------------------------

ShawvcrA#3              TATTTACCTGGTTTAAAAAGAATAATATCACTTTAAAGTGGAATGAGTGGGTACTTG-CA 1420
ShawvcrA#5              TATTTACCTGGTTTAAAAAGAATAATATCACTTTAAAGTGGAATGAGTGGGTACTTG-CA 1419
ShawvcrA#1              TATTTACCTGGTTTAAAAAGAATAATATCACTTTAAAGTGGAATGAGTGGGTACTTG-CA 1420
ShawvcrA#2              TATTTACCTGGTTTAAAAAGAATAATATCACTTTAAAGTGGAATGAGTGGGTACTTG-CA 1431
OperonfromStrainVS      TATTTACCTGGTTTAAAAAGAATAATATCACTTTAAAGTGGAATGAGTGGGTACTTGGCA 2337
vcrAKB1RdhAB14          ------------------------------------------------------------

ShawvcrA#3              TATTGGGGCTGTTACAAGGGC--------------------------------------- 1441
ShawvcrA#5              TATTGGGGCTGTTAAGGGGGTAATCTTGGGCATATCTGTTTCCTGAG------------- 1466
ShawvcrA#1              TATTGGGGCTGTTACAAGGGC--------------------------------------- 1441
ShawvcrA#2              TATTGGGGCTGTTACAAGGGC--------------------------------------- 1452
OperonfromStrainVS      TATTGGGGCTGTTACTAGCTTTGTTTGCTATTCAACACACATATGCCAGTGCTACATATG 2397
vcrAKB1RdhAB14          ------------------------------------------------------------
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Appendix E
Well Logs and Well Completion Information

Appendix E.1
Lithologic Logs

Boring/ Well No.: AEW1	**Site/Location:** Naval Weapons Station, Seal Beach		
Client: NFESC (Naval Facilities Eng. Serv. Ctr.)	**Project No.:** 50999-56254-6225.001.TK4.EQUIP		**Page** 1 **of** 2
Drill Contractor: RSI Drilling	**Drill Method:** Hollow Stem Auger		**Elevation:**
Date Started: 9/12/07	**Sampling Method:** CA-Modified Split Spoon – CC		
Date Ended: 9/12/07	**Total Depth:**	**Remarks:**	
On-site Geologist: Kristeen Bennett	**Depth to Water:**		

Depth (feet)	Blow Count	Recovery (feet)	PID (ppm)	USCS	Description	Well Construction Detail
	Not Measured				4" Asphalt cored (18" diameter) 4' Road base (sand/gravel mixture) 4-5' Native clay (see below)	
5		56"/60"	2.3 10.0 24.5 2.4	CL	5-7.5: Clay: Black (7.5YR2.5/1) 85% moderately plastic clay; 10% f. to c., SA, poorly graded sand; 5% micaceous silt; dry. 7.5-10: similar to above w/ change in color to very dark grayish brown (2.5Y3/2) w/ organic material and light gray (2.5Y7/1) clay balls	
10		55"/60"	3.9 18.3 5.0 60.0	CL/SC	10-12.5 - similar to above 12.5-15: Clay w/ Sand; Dark grayish brown (2.5Y4/2); 60% moderately plastic clay; 30% f. sand, SR, well graded; 10% micaceous silt; some laminar bedding; Fe-oxide mottling; organic debris	
15		60"/60"	2.7 4.2 1.8 3.7	SC	15-19.5 - similar to above 19.5-20 - Clayey Sand; Dark olive gray (5Y3/2); 55% f. to m. sand, SR, poorly graded; 35% plastic clay; 10% micaceous silt; moist.	
20		48"/60"	7.4 7.4 1.2 7.2	SM	20(?)-25: Silty Sand; Olive gray (5Y4/2); 65% f. to m. sand, SR, well graded, 25% micaceous silt; 10% plastic clay; laminar bedding; moist.	
25		31"/60"	0.2 1.4 2.1 0.3	SM/ML	25-30 (?) - similar to above but wet and increasing silt	
30						

CDM

BORING LOG AND SAMPLING RECORD

Boring/ Well No.: AEW1	**Site/Location:** Naval Weapons Station, Seal Beach		
Client: NFESC (Naval Facilities Eng. Serv. Ctr.)	**Project No.:** 50999-56254-6225.001.TK4.EQUIP		**Page** 2 **of** 2
Drill Contractor: RSI Drilling	**Drill Method:** Hollow Stem Auger		**Elevation:**
Date Started: 9/12/07	**Sampling Method:** CA-Modified Split Spoon		
Date Ended: 9/12/07	**Total Depth:**	**Remarks:**	
On-site Geologist: Kristeen Bennett	**Depth to Water:**		

Depth (feet)	Blow Count	Recovery (feet)	PID (ppm)	USCS	Description	Well Construction Detail
35		37"/60"	1.3 8.7		35-37 - No recovery → Silt? 37-39': Clay w/ Gravel: Olive (5Y4/3), 50% plastic clay; 25% f. to m., SA to SR gravel; 15% micaceous silt; 10% f. to c., SA to SR sand, poorly graded gravel; wet. 39-40' - Similar to 25-30'	
40					T.D. of borehole = 35 ft. bgs T.D. of well	

CDM **BORING LOG AND SAMPLING RECORD**

Boring/ Well No.: AIW2	**Site/Location:** Naval Weapons Station, Seal Beach		
Client: NFESC (Naval Facilities Eng. Serv. Ctr.)	**Project No.:** 50999-56254-6225.001.TK4.EQUIP	**Page** 1 **of** 2	
Drill Contractor: RSI Drilling	**Drill Method:** Hollow Stem Auger	**Elevation:**	
Date Started: 9/11/07	**Sampling Method:** CA-Modified Split Spoon		
Date Ended: 9/11/07	**Total Depth:** 35.1 4 bags	**Remarks:**	
On-site Geologist: Kristeen Bennett	**Depth to Water:**		

Depth (feet)	Blow Count	Recovery (feet)	PID (ppm)	USCS	Description	Well Construction Detail
5	Not measured				3" Asphalt cored 18" diameter 5' of road base removed (sand/gravel mixture) Hand augered to 8 ft. bgs	
		20"/60"	0.7 1.0 0.7		8.5-9.0 (?) → Road base → Gravelly Sand: Olive brown (2.5Y5/4); 20% f. to c., poorly graded, SA gravel; 60% f. to c., poorly graded, SA to SR sand; 15% micaceous silt; 5% plastic clay.	
10		52"/60"	6.0 6.0 6.0 0.4	CL/ML	9.0-10.0 (?) Silty Clay; Black (2.5Y2.5/1); 70% moderately plastic clay; 25% micaceous silt; 5% f. to m. sand, well graded; SA to SR; moist.	
15					-10-11.5 similar to above w/ change in color to Olive brown (2.5Y4/3)	
		60"/60"	0.3 0.7	SC	-11.5-13 similar to above w/ change in color to Very dark grayish brown (2.5Y3/2)	
20			26.1 9.6		13-15 (?) Sandy Clay: Dark yellowish brown (10YR 3/4); 50% moderately plastic clay; 30% f. to c. sand, poorly graded SA to SR; 20% micaceous silt; moist; Fe-oxide mottling w/ organic debris "balls".	
			2.3 4.1	CL	15-17 - similar to above w/ more f. to m. sand (40%)	
		54"/60"	4.7 2.1	ML	17-18.5 - similar to above w/ change in color to Very dark grayish brown (10YR 3/2)	
25					18.5-20': Clay w/ Sand: Light gray (5Y7/2); 75% plastic, friable (?) clay; 15% f. to m. sand, SA to SR, well graded; 10% micaceous silt; moist.	
		44"/60"	0.7 0.3	SM	20-21.5 - similar to 15-17.	
30			4.1	ML	21.5-22.5 - similar 18.5-20"	

CDM **BORING LOG AND SAMPLING RECORD**

Boring/ Well No.: AIW2	**Site/Location:** Naval Weapons Station, Seal Beach		
Client: NFESC (Naval Facilities Eng. Serv. Ctr.)	**Project No.:** 50999-56254-6225.001.TK4.EQUIP		**Page** 1 **of** 2
Drill Contractor: RSI Drilling	**Drill Method:** Hollow Stem Auger		**Elevation:**
Date Started: 9/11/07	**Sampling Method:** CA-Modified Split Spoon		
Date Ended: 9/11/07	**Total Depth:** 35.1	**Remarks:**	
On-site Geologist: Kristeen Bennett	**Depth to Water:**		

Depth (feet)	Blow Count	Recovery (feet)	PID (ppm)	USCS	Description	Well Construction Detail
3 5	Not measured	47"/60"	0.3 0.1 0.0 2.2	ML/CL ML	22.5-24.5: Silt: Olive (5Y4/3) 80% micaceous silt; 15% plastic clay; 5% f. sand; SR, well graded; wet -24-24.2 - Sandy clay lense similar to 21.5-22.5 24.5-28(?) Silty Sand: Olive (5Y4/4); 65% f. sand; well graded, SR; 15% micaceous silt; 150% plastic clay; wet 28(?)-30 Silt; Olive (5Y4/3); 90% micaceous silt; 10% plastic clay; wet 30-33(?); Silty Clay: Olive gray (5Y4/2); 60% plastic clay; 40% micaceous silt; wet; heavy bioturbation (?) 33-35(?) - similar to 28-30' T.D. of boring = 35.1 ft. bgs	

CDM

BORING LOG AND SAMPLING RECORD

Boring/ Well No.: AIW1	**Site/Location:** Naval Weapons Station, Seal Beach		
Client: NFESC (Naval Facilities Eng. Serv. Ctr.)	**Project No.:** 50999-56254-6225.001.TK4.EQUIP		**Page** 2 **of** 2
Drill Contractor: RSI Drilling	**Drill Method:** Hollow Stem Auger		**Elevation:**
Date Started: 9/10/07	**Sampling Method:** CA-Modified Split Spoon		
Date Ended: 9/10/07	**Total Depth:** 35	**Remarks:**	
On-site Geologist: Kristeen Bennett	**Depth to Water:**		

Depth (feet)	Blow Count	Recovery (feet)	PID (ppm)	USCS	Description	Well Construction Detail
35	Not measured	60"/60"	6.5 3.2 0.8 2.1	my/sm	22.8-24.5'; Silty clay: Olive (5Y5/3) 50% plastic clay; 40% micaceous silt; 10% f. to m. sand, SA, well graded;	
					24.5-25: similar to 15.5 to 18.	
					26-28.8 (?): Silty Sand: Olive gray (5Y4/2) 70% f. to m. sand, SR; well graded; 25% micaceous silt; 5% plastic clay; wet; Fe-oxide mottling.	
40					28.8 (?)-35; Sandy Silt; Olive gray (5Y4/2); 60% micaceous silt; 25% f. sand, well graded, SR; <5% plastic clay; <5% f. to m. gravel (as lenses) SA; wet.	
5						
					T.D. of boring (w/ slough) = 35ft. bgs	
0					T.D. of bottom of well =	
5						
0						

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BORING LOG AND SAMPLING RECORD

Boring/ Well No.: AIW1	**Site/Location:** Naval Weapons Station, Seal Beach		
Client: NFESC (Naval Facilities Eng. Serv. Ctr.)	**Project No.:** 50999-56254-6225.001.TK4.EQUIP		**Page** 1 **of** 2
Drill Contractor: RSI Drilling	**Drill Method:** Hollow Stem Auger		**Elevation:**
Date Started: 9/10/07	**Sampling Method:** CA-Modified Split Spoon		
Date Ended:	**Total Depth:** 35 ft. bgs	**Remarks:**	
On-site Geologist: Kristeen Bennett	**Depth to Water:**		

Depth (feet)	Blow Count	Recovery (feet)	PID (ppm)	USCS	Description	Well Construction Detail
	Not measured		0.0/0.0		2½" asphalt Cored 4.5' road base (sand/gravel mix)	
5			0.0	CL/ML	5-5.5 (?) Silty Clay: Very dark grayish brown (2.5Y3/2); 60% plastic to moderately stiff clay; 30% micaceous silt; 10% f. sand;	
		24"/60"	0.2 0.3	CL	5.5-7.2 (10.2)? Clay: Very dark gray (2.5Y3/1); 80% moderately stiff clay; 20% micaceous silt.	
10			0.0	CL		
		60"/60"	0.3 0.2	CL	10.2-12.2: similar to above w/ change in color to olive brown (2.5Y4/3)	
			0.0 0.0	CL SC	12.2-13.2: similar to above w/ change in color to very dark grayish brown (2.5Y3/2).	
15				CL		
		60"/60"	0.3 0.2	SC	13.2-15.5 similar to above w/ change in color to olive brown (2.5Y4/3) thin coarse sand and gravel lenses throughout.	
			8.8	CL	15.5-18: Clayey Sand: Brown (10YR4/3) 60% f. to m. sand, well graded, SA to SR; 35% stiff clay; 5% micaceous silt; Fe-oxide mottling; few worm casings.	
20			22.9			
		60"/60"	58.7	CL/SC	18-18.8: similar to 12.2 to 13.2 * abrupt physical change	
			13.7	SC		
			8.2	CL/ML	18.8-20.5: Sandy Clay: Light gray (2.5Y7/2); 65% friable (?) plastic clay; 35% f. to c. SA poorly graded sand; <5% micaceous clay; <1% f. angular gravel; heavily bioturbated (?) * look like bentonite at bed	
25			22.8	SC		
		46"/60"	13.1 93.2	SM	20.5-22.8: Clayey Sand; Pale yellow (2.5Y7/3); 50% f. to c. sand, SA, poorly graded; 30% micaceous silt; 15% plastic clay; 5% f. to m. gravel, SA; moist; somewhat friable.	
			7.8 85.7	ML/SM		
30						

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BORING LOG AND SAMPLING RECORD

Boring/ Well No.: AEW2	**Site/Location:** Naval Weapons Station, Seal Beach		
Client: NFESC (Naval Facilities Eng. Serv. Ctr.)	**Project No.:** 50999-56254-6225.001.TK4.EQUIP	**Page** 1 **of** 2	
Drill Contractor: RSI Drilling	**Drill Method:** Hollow Stem Auger	**Elevation:**	
Date Started: 9/11/07	**Sampling Method:** CA-Modified Split Spoon		
Date Ended: 9/12/07	**Total Depth:**	**Remarks:**	
On-site Geologist: Kristeen Bennett	**Depth to Water:**		

Depth (feet)	Blow Count	Recovery (feet)	PID (ppm)	USCS	Description	Well Construction Detail
5	Not Measured				3"-thick asphalt cored 18" diam. ~4'-thick road base (sand/gravel mixture)	
		36"/60"	0.2 0.2 0.2		7.5-8: Gravelly Sand: Dark brown (10YR3/3); 60% f. to c., SA to SR, poorly graded sand; 15% micaceous silt; 15% plastic clay; 10% f. to m. SA gravel; dry.	
10			40.0	CL	8-12.5: Clay: Black (10YR2/1); 85% moderately plastic clay; 15% micaceous silt; dry; organic material; worm casings.	
		60"/60"	0.2 0.2 0.2		12.5-18: Sandy Clay: Dark grayish brown (10YR4/2); 65% moderately plastic clay; 25% f. to m., SA to SR, poorly graded; 10% micaceous silt; some organic material; Fe-oxide mottling especially near sands.	
15			54.3	SC		
		33"/60"	0.2 10.3 0.7 0.2	SC	18-20: Sandy Clay: Very pale brown (10YR8/2); 65% friable (?) plastic clay; 30% f. to c., poorly graded, SA sand; 5% micaceous silt; dry. ▽ ? -3" beds of Olive (5Y5/3) micaceous silt @ 18.5 and 19.8.	
20						
		42"/60"	5.2 16.0	SP/SM	20(?)-23.5: Sandy Silt: Olive (5Y 4/4); 80% f. to m. sand, well graded SA to SR; 15% micaceous silt; 5% plastic clay; wet; some Fe-oxide staining.	
			12.4 0.3			
25						
		48"/60"	0.2 0.3 0.0 16.9	SM	23.5-25: Sandy Silt: Olive (5Y 4/3); 70% micaceous silt; 25% f. sand, SR, well graded; 5% plastic clay; moist. -25(?)-30: Similar to above w/ more fine sand -caliche nodule(?) @ 29'	
30						

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BORING LOG AND SAMPLING RECORD

Boring/ Well No.: AEW2	**Site/Location:** Naval Weapons Station, Seal Beach		
Client: NFESC (Naval Facilities Eng. Serv. Ctr.)	**Project No.:** 50999-56254-6225.001.TK4.EQUIP	**Page** 2 **of** 2	
Drill Contractor: RSI Drilling	**Drill Method:** Hollow Stem Auger	**Elevation:**	
Date Started: 9/11/07	**Sampling Method:** CA-Modified Split Spoon		
Date Ended: 9/12/07	**Total Depth:** 35 ft bgs	**Remarks:**	
On-site Geologist: Kristeen Bennett	**Depth to Water:**		

Depth (feet)	Blow Count	Recovery (feet)	PID (ppm)	USCS	Description	Well Construction Detail
35	Not measured	60"/60"	0.5 0.2 2.5 3.3	SM / ML	30-35': similar to above 33-laminar bedding @ 34'	
40						
5						
0						
5					T.D. of bore hole 35 ft bgs (w/sloughs)	
0						

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BORING LOG AND SAMPLING RECORD

Appendix E.2
Phase I Well Logs

CDM
111 Academy, Suite 150
Irvine, CA 92617
Phone: (949) 752-5452
Fax: (949) 725-3907

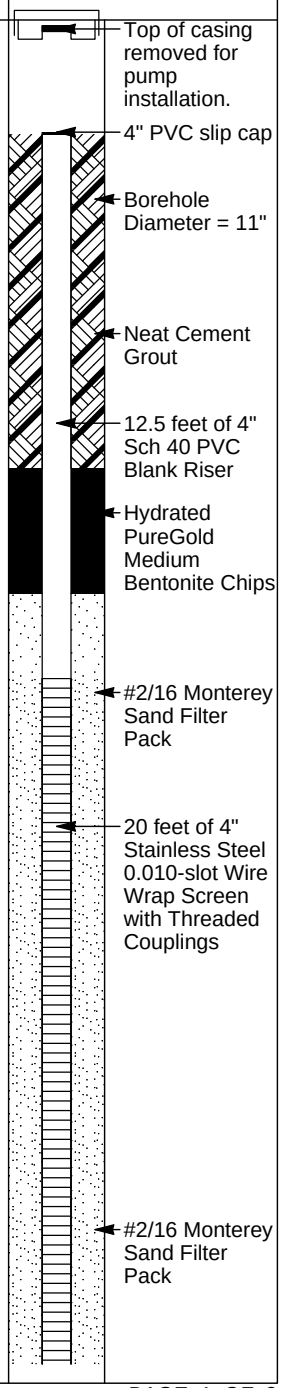
BORING/WELL CONSTRUCTION LOG

PROJECT NUMBER 50999-56254-6225.001.TK4.EQUIP
PROJECT NAME Naval Weapons Station-Seal Beach, Site 70
LOCATION Naval Weapons Station-Seal Beach
DRILLING METHOD CME 75 Hollow Stem Auger
SAMPLING METHOD 4' Split Spoon-Continuous Core
GROUND SURFACE ELEVATION (FT MSL)
TOP OF CASING ELEVATION (FT MSL)
LOGGED BY Kristeen Bennett
REMARKS

BORING/WELL NUMBER AEW1
DATE DRILLED 9/12/07
CASING TYPE/DIAMETER 4" Schedule 40 PVC
SCREEN TYPE/SLOT 4" Stainless Steel Wire Wrap/0.010-slot
GRAVEL PACK TYPE #2/16 Monterey Sand
GROUT TYPE/QUANTITY Neat Cement Grout / Medium Bentonite Chips
STATIC WATER LEVEL (FT BELOW TOC)
GROUND WATER ELEVATION (FT MSL)

PID (ppm)	BLOW COUNTS	RECOVERY (inches)	DEPTH (feet bgs)	U.S.C.S.	GRAPHIC LOG	LITHOLOGIC DESCRIPTION	CONTACT DEPTH
						4" Asphalt cored (18" diameter)	0.3
						Hand augered to 5 feet bgs for utility clearance. ~4' of road base (Silty Sand-Gravel mixture)	
							4.0
2.3 10.0 24.5 2.4	NM	56"/60"	5	CL		4-7.5: CLAY: Black (7.5YR2.5/1); 85% moderately plastic clay; 10% fine to coarse, subangular, poorly graded sand, 5% micaceous silt; moist.	
						7.5-10: similar to above with change in color to very dark grayish brown (2.5Y3/2) with organic material and light gray (2.5Y7/1) clay "balls."	
3.9 18.3 5.0 66.0	NM	55"/60"	10			10-12.5: Similar to above	
							12.5
						12.5-15: SANDY CLAY: Dark grayish brown (2.5Y4/2); 60% moderately plastic clay; 30% fine, subround, well graded sand; 10% micaceous silt; some laminar bedding; iron oxide mottling; organic debris.	
2.7 4.2 1.8 3.7	NM	60"/60"	15	SC		15-19.5: Similar to above	
							20.0
7.4 7.4 1.2 7.2	NM	48"/60"	20			19.5-20: VERY CLAYEY SAND: Dark olive gray (5Y3/2); 55% fine to medium sand, subround, poorly graded; 35% plastic clay; 10% micaceous silt; wet. 20-25: SILTY SAND: Olive gray (5Y4/2); 65% fine to medium sand, subround, well graded; 25% micaceous silt; 10% plastic clay; laminar bedding; wet.	
0.2 1.4 2.1 0.3	NM	31"/60"	25	SM		25-30: Similar to above with increasing silt and wet.	
			30				30.0

Continued Next Page



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111 Academy, Suite 150
Irvine, CA 92617
Phone: (949) 752-5452
Fax: (949) 725-3907

BORING/WELL CONSTRUCTION LOG

PROJECT NUMBER 50999-56254-6225.001.TK4.EQUIP **BORING/WELL NUMBER** AEW1

PROJECT NAME Naval Weapons Station-Seal Beach, Site 70 **DATE DRILLED** 9/12/07

Continued from Previous Page

PID (ppm)	BLOW COUNTS	RECOVERY (inches)	DEPTH (feet bgs)	U.S.C.S.	GRAPHIC LOG	LITHOLOGIC DESCRIPTION	CONTACT DEPTH	WELL DIAGRAM
1.3 8.7	NM	37"/60"				30-32: No Recovery (Silt?)		
							32.0	
				GC		32-34: GRAVELLY CLAY: Olive (5Y4/3); 50% plastic clay; 25% fine to medium, subangular to subround gravel; 15% micaceous silt; 10% fine to coarse, subangular to subround, poorly graded sand; saturated.		
							34.0	
				SM		34-35: Similar to 25-30'.		
			35				35.0	
						Total Depth of Borehole: 35 feet bgs Total Depth of Well: 34.7 feet bgs		
			40					
			45					
			50					
			55					
			60					

#2/16 Monterey Sand Filter Pack

Welded Stainless Steel bottom plate Slough

SEALBEACH SEALBEACH.GPJ NEWGINT.GDT 10/24/07

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111 Academy, Suite 150
Irvine, CA 92617
Phone: (949) 752-5452
Fax: (949) 725-3907

BORING/WELL CONSTRUCTION LOG

PROJECT NUMBER 50999-56254-6225.001.TK4.EQUIP
PROJECT NAME Naval Weapons Station-Seal Beach, Site 70
LOCATION Naval Weapons Station-Seal Beach
DRILLING METHOD CME 75 Hollow Stem Auger
SAMPLING METHOD 4' Split Spoon-Continuous Core
GROUND SURFACE ELEVATION (FT MSL)
TOP OF CASING ELEVATION (FT MSL)
LOGGED BY Kristeen Bennett
REMARKS

BORING/WELL NUMBER AEW2
DATE DRILLED 9/11/07
CASING TYPE/DIAMETER 4" Schedule 40 PVC
SCREEN TYPE/SLOT 4" Stainless Steel Wire Wrap/0.010-slot
GRAVEL PACK TYPE #2/16 Monterey Sand
GROUT TYPE/QUANTITY Neat Cement Grout / Medium Bentonite Chips
STATIC WATER LEVEL (FT BELOW TOC)
GROUND WATER ELEVATION (FT MSL)

PID (ppm)	BLOW COUNTS	RECOVERY (inches)	DEPTH (feet bgs)	U.S.C.S.	GRAPHIC LOG	LITHOLOGIC DESCRIPTION	CONTACT DEPTH
						3" Asphalt cored (18" diameter)	0.3
						Hand augered to 5 feet bgs for utility clearance. ~7.5' of road base (Silty Sand-Gravel mixture)	
0.2 0.2 0.2 40.0	NM	36"/60"	5				
				SP		7.5-8.0: CLAYEY SILTY SAND: Dark brown (10YR3/3); 60% fine to coarse, subangular to subround, poorly graded sand; 15% micaceous silt; 15% plastic clay; 10% fine to medium, subangular gravel; moist.	7.5 8.0
0.2 0.2 0.2 54.3	NM	60"/60"	10	CH		8-12.5: SILTY CLAY: Black (10YR2/1); 85% moderately plastic clay; 15% micaceous silt; moist; organic material; worm casings.	
						12.5-18: SANDY CLAY: Dark grayish brown (10YR4/2); 65% moderately plastic clay; 25% fine to medium, subangular to subround, poorly graded sand; 10% micaceous silt; trace organic material; iron oxide mottling, especially near sands.	12.5
0.2 0.3 0.7 0.2	NM	53"/60"	15	CH			
						18-20: VERY SANDY CLAY: Very pale brown (10YR8/2); 65% platy, plastic clay; 30% fine to coarse, poorly graded, subangular sand; 5% micaceous silt; moist.	18.7
						3" layer of Olive (5Y5/3) micaceous silt @ 18.5' and 19.5'.	19.7
5.2 16.0 12.4 0.3	NM	42"/60"	20	SW SM		20-23.5: SILTY SAND: Olive (5Y4/4); 80% fine to medium, well graded, subangular to subround sand; 15% micaceous silt; 5% plastic clay; saturated; some iron oxide mottling.	20.0
						23.5-25: SANDY SILT: Olive (5Y4/3); 70% micaceous silt; 25% fine, subround, well graded sand; 5% plastic clay; wet.	23.5
0.2 0.3 0.0 16.9	NM	48"/60"	25	SM		25-30: Similar to above w/ increasing fine sand.	
						Caliche nodule(s) from 29'-29.3'.	29.3
			30				30.0

Continued Next Page

WELL DIAGRAM
- Top of casing removed for pump installation.
- 4" PVC slip cap
- Borehole Diameter = 11"
- Neat Cement Grout
- 12.5 feet of 4" Sch 40 PVC Blank Riser
- Hydrated PureGold Medium Bentonite Chips
- #2/16 Monterey Sand Filter Pack
- 20 feet of 4" Stainless Steel 0.010-slot Wire Wrap Screen with Threaded Couplings
- #2/16 Monterey Sand Filter Pack

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111 Academy, Suite 150
Irvine, CA 92617
Phone: (949) 752-5452
Fax: (949) 725-3907

BORING/WELL CONSTRUCTION LOG

PROJECT NUMBER 50999-56254-6225.001.TK4.EQUIP **BORING/WELL NUMBER** AEW2

PROJECT NAME Naval Weapons Station-Seal Beach, Site 70 **DATE DRILLED** 9/11/07

Continued from Previous Page

PID (ppm)	BLOW COUNTS	RECOVERY (inches)	DEPTH (feet bgs)	U.S.C.S.	GRAPHIC LOG	LITHOLOGIC DESCRIPTION	CONTACT DEPTH	WELL DIAGRAM
0.5 0.2 2.5 3.3	NM	60"/60"		SM		30-35: Similar to above with laminar bedding from 34'-35'.	35.0	#2/16 Monterey Sand Filter Pack
			35			Total Depth of Boring = 35 feet bgs (with slough) Total Depth of Well = 35.3 feet bgs		Slough Welded Stainless Steel bottom plate
			40					
			45					
			50					
			55					
			60					

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Irvine, CA 92617
Phone: (949) 752-5452
Fax: (949) 725-3907

BORING/WELL CONSTRUCTION LOG

PROJECT NUMBER 50999-56254-6225.001.TK4.EQUIP
PROJECT NAME Naval Weapons Station-Seal Beach, Site 70
LOCATION Naval Weapons Station-Seal Beach
DRILLING METHOD CME 75 Hollow Stem Auger
SAMPLING METHOD 4' Split Spoon-Continuous Core
GROUND SURFACE ELEVATION (FT MSL)
TOP OF CASING ELEVATION (FT MSL)
LOGGED BY Kristeen Bennett
REMARKS

BORING/WELL NUMBER AIW1
DATE DRILLED 9/10/07
CASING TYPE/DIAMETER 4" Schedule 40 PVC
SCREEN TYPE/SLOT 4" Stainless Steel Wire Wrap/0.010-slot
GRAVEL PACK TYPE #2/16 Monterey Sand
GROUT TYPE/QUANTITY Neat Cement Grout / Medium Bentonite Chips
STATIC WATER LEVEL (FT BELOW TOC)
GROUND WATER ELEVATION (FT MSL)

PID (ppm)	BLOW COUNTS	RECOVERY (inches)	DEPTH (feet bgs)	U.S.C.S.	LITHOLOGIC DESCRIPTION	CONTACT DEPTH
0.0/0.0					2.5" Asphalt cored (18" diameter) Hand augered to 5 feet bgs for utiltiy clearance. ~4.5' of road base (Silty Sand-Gravel mixture)	0.2
0.0 0.2 0.3 0.0	NM	24"/60"	5	CL ML	5-5.5: SILTY CLAY: Very dark grayish brown (2.5Y3/2); 60% plastic to moderately stiff clay; 30% micaceous silt; 10% fine sand. 5.5-10.2: SILTY CLAY: Very dark gray (2.5Y3/1); 80% moderately stiff clay; 20% micaceous silt.	5.0 5.5
0.3 0.2 0.0 0.0	NM	60"/60"	10	CL	10.2-12.2: Similar to above with change in color to Olive brown (2.5Y4/3). 12.2-13.2: Similar to above with change in color to Very dark grayish brown (2.5Y3/2). 13.2-15.5: Similar to above with change in color to Olive brown (2.5Y4/3) with thin, coarse sand and gravel layers throughout.	
0.3 0.2 8.8 22.9	NM	60"/60"	15	SC	15.5-18: VERY CLAYEY SAND: Brown (10YR4/3); 60% fine to medium, well graded, subangular to subround sand; 35% stiff clay; 5% micaceous silt; iron oxide mottling; few worm casings.	15.5
				SC	18-18.8: Similar to 12.2 to 13.2 with abrupt physical change.	18.0 18.8
58.7 13.7 8.2 22.8	NM	60"/60"	20	CL SC	18.8-20.5: VERY SANDY CLAY: Light gray (2.5Y7/2); 65% platy, plastic clay; 35% fine to coarse, poorly graded, subangular sand; <5% micaceous silt; <1% fine, angular gravel; heavily bioturbated. 20.5-22.8: CLAYEY SAND: Pale yellow (2.5Y7/3); 50% fine to coarse, subangular, poorly graded sand; 30% micaceous silt; 15% platy, plastic clay; 5% fine to medium, subangular gravel; moist.	20.5 22.8
				CL ML SC	22.8-24.5: SILTY CLAY: Olive (5Y5/3); 50% plastic clay; 40% micaceous silt; 10% fine to medium, well graded, subangular sand. 24.5-25: Similar to 15.5 to 18.	24.5 25.0
13.1 93.2 7.8 85.7	NM	46"/60"	25		25-26: No Recovery.	26.0
				SM	26-28.8: SILTY SAND: Olive gray (5Y4/2); 70% fine to medium, subround, well graded sand; 25% micaceous silt; 5% plastic clay; saturated; some iron oxide mottling.	28.8
			30		28.8-35: SANDY SILT: Olive gray (5Y4/2); 60% micaceous silt; 25% fine, well graded, subround sand;	

Continued Next Page

WELL DIAGRAM

- Top of casing removed for pump installation.
- 4" PVC slip cap
- Borehole Diameter = 11"
- Neat Cement Grout
- 12.5 feet of 4" Sch 40 PVC Blank Riser
- Hydrated PureGold Medium Bentonite Chips
- #2/16 Monterey Sand Filter Pack
- 20 feet of 4"Stainless Steel 0.010-slot Wire Wrap Screen with Threaded Couplings
- #2/16 Monterey Sand Filter Pack

SEALBEACH SEALBEACH.GPJ NEWGINT.GDT 10/24/07

CDM
111 Academy, Suite 150
Irvine, CA 92617
Phone: (949) 752-5452
Fax: (949) 725-3907

BORING/WELL CONSTRUCTION LOG

PROJECT NUMBER 50999-56254-6225.001.TK4.EQUIP **BORING/WELL NUMBER** AIW1

PROJECT NAME Naval Weapons Station-Seal Beach, Site 70 **DATE DRILLED** 9/10/07

Continued from Previous Page

PID (ppm)	BLOW COUNTS	RECOVERY (inches)	DEPTH (feet bgs)	U.S.C.S.	GRAPHIC LOG	LITHOLOGIC DESCRIPTION	CONTACT DEPTH	WELL DIAGRAM
6.5 3.2 0.8 2.1	NM	60"/60"		SM ML		<5% clay; <5% fine to medium, subangular gravel (as layers); saturated.		#2/16 Monterey Sand Filter Pack
			35				35.0	Welded Stainless Steel bottom plate
						Total Depth of Boring = 35 feet bgs Total Depth of Well = 35 feet bgs		
			40					
			45					
			50					
			55					
			60					

SEALBEACH SEALBEACH.GPJ NEWGINT.GDT 10/24/07

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111 Academy, Suite 150
Irvine, CA 92617
Phone: (949) 752-5452
Fax: (949) 725-3907

BORING/WELL CONSTRUCTION LOG

PROJECT NUMBER 50999-56254-6225.001.TK4.EQUIP
PROJECT NAME Naval Weapons Station-Seal Beach, Site 70
LOCATION Naval Weapons Station-Seal Beach
DRILLING METHOD CME 75 Hollow Stem Auger
SAMPLING METHOD 4' Split Spoon-Continuous Core
GROUND SURFACE ELEVATION (FT MSL)
TOP OF CASING ELEVATION (FT MSL)
LOGGED BY Kristeen Bennett
REMARKS

BORING/WELL NUMBER AIW2
DATE DRILLED 9/11/07
CASING TYPE/DIAMETER 4" Schedule 40 PVC
SCREEN TYPE/SLOT 4" Stainless Steel Wire Wrap/0.010-slot
GRAVEL PACK TYPE #2/16 Monterey Sand
GROUT TYPE/QUANTITY Neat Cement Grout / Medium Bentonite Chips
STATIC WATER LEVEL (FT BELOW TOC)
GROUND WATER ELEVATION (FT MSL)

PID (ppm)	BLOW COUNTS	RECOVERY (inches)	DEPTH (feet bgs)	U.S.C.S.	GRAPHIC LOG	LITHOLOGIC DESCRIPTION	CONTACT DEPTH
						3" Asphalt cored (18" diameter)	0.3
						Hand augered to 6 feet bgs for utility clearance. ~5' of road base (Silty Sand-Gravel mixture)	
						Hand augered to 8 feet bgs.	
0.7 1.0 0.7	NM	20"/60"	5				
						ROAD BASE: GRAVELLY SILTY SAND: Olive brown (2.5Y5/4); 20% fine to coarse, subangular, poorly graded gravel; 60% fine to coarse, poorly graded, subangular to subround sand; 15% micaceous silt; 5% plastic clay.	8.5
0.0 0.0 0.0 0.4	NM	52"/60"	10	CL ML		9-10: SILTY CLAY: Black (2.5Y2.5/1); 70% moderately plastic clay; 25% micaceous silt; 5% fine to medium, well graded, subangular to subround sand; wet. 10-11.5: Similar to above with change in color to Olive brown (2.5Y4/3). 11.5-13: Similar to above with change in color to Very dark grayish brown (2.5Y3/2).	13.0
0.3 0.7 26.1 9.6	NM	60"/60"	15	CL		13-15: SANDY SILTY CLAY: Dark yellowish brown (10YR3/4); 50% moderately plastic clay; 30% fine to coarse, poorly graded, subangular to subround sand; 20% micaceous silt; wet; iron oxide mottling with organic debris. 15-17: Similar to above with more fine to medium sand (40%). 17-18.5: Similar to above with change in color to Very dark grayish brown (10YR3/2).	18.5
				CL		18.5-20: SILTY SANDY CLAY: Light gray (5Y7/2); 75% plastic, platy clay; 15% fine to medium, subanguilar to subround, well graded sand; 10% micaceous silt; wet.	20.0
2.3 4.1 4.7 2.1	NM	54"/60"	20	CL		20-21.5: Similar to 15'-17'. 21.5-22.5: Similar to 18.5'-20'.	22.5
				ML CL		22.5-24.5: CLAYEY SILT: Olive (5Y4/3); 80% micaceous silt; 15% plastic clay; 5% fine, subround, well graded sand; saturated. 24-24.2: Sandy clay layer similar to 18.5'-20'.	24.2 24.5
0.7 0.3 4.1	NM	44"/60"	25	SM		24.5-28: SILTY SAND: Olive (5Y4/4); 65% fine, well graded, subround sand; 25% micaceous silt; 10% plastic clay; saturated.	28.0
				ML		28-30: SILT: Olive (5Y4/3); 90% micaceous silt; 10% plastic clay; saturated.	30.0
			30				

Continued Next Page

WELL DIAGRAM

- Top of casing removed for pump installation.
- 4" PVC slip cap
- Borehole Diameter = 11"
- Neat Cement Grout
- 12.5 feet of 4"-diameter Sch 40 PVC Blank Riser
- Hydrated PureGold Medium Bentonite Chips
- #2/16 Monterey Sand Filter Pack
- 20 feet of 4"-diameter Stainless Steel 0.010-slot Wire Wrap Screen with Threaded Couplings
- #2/16 Monterey Sand Filter Pack

SEALBEACH SEALBEACH.GPJ NEWGINT.GDT 10/24/07

CDM
111 Academy, Suite 150
Irvine, CA 92617
Phone: (949) 752-5452
Fax: (949) 725-3907

BORING/WELL CONSTRUCTION LOG

PROJECT NUMBER 50999-56254-6225.001.TK4.EQUIP **BORING/WELL NUMBER** AIW2

PROJECT NAME Naval Weapons Station-Seal Beach, Site 70 **DATE DRILLED** 9/11/07

Continued from Previous Page

PID (ppm)	BLOW COUNTS	RECOVERY (inches)	DEPTH (feet bgs)	U.S.C.S.	GRAPHIC LOG	LITHOLOGIC DESCRIPTION	CONTACT DEPTH	WELL DIAGRAM
0.3 0.1 0.0 2.2	NM	47"/60"		CL ML		30-33: VERY SILTY CLAY: Olive gray (5Y4/2); 60% plastic clay; 40% micaceous silt; saturated; heavy bioturbation.		#2/16 Monterey Sand Filter Pack
							33.0	
				ML		33-35: Similar to 28'-30'.		
			35				35.0	Slough Welded Stainless Steel bottom plate
						Total Depth of Boring = 35.1 feet bgs (with slough) Total Depth of Well = 35.6 feet bgs		
			40					
			45					
			50					
			55					
			60					

SEALBEACH SEALBEACH.GPJ NEWGINT.GDT 10/24/07

CDM
111 Academy, Suite 150
Irvine, CA 92617
Phone: (949) 752-5452
Fax: (949) 725-3907

BORING/WELL CONSTRUCTION LOG

PROJECT NUMBER 50999-56254-6225.001.TK4.EQUIP
PROJECT NAME Naval Weapons Station-Seal Beach, Site 70
LOCATION Naval Weapons Station-Seal Beach
DRILLING METHOD CME 75 Hollow Stem Auger
SAMPLING METHOD 1.5' CA-Modified Split Spoon
GROUND SURFACE ELEVATION (FT MSL)
TOP OF CASING ELEVATION (FT MSL)
LOGGED BY Kristeen Bennett
REMARKS

BORING/WELL NUMBER AMW1
DATE DRILLED 9/5/07
CASING TYPE/DIAMETER 4" Schedule 40 PVC
SCREEN TYPE/SLOT 4" Schedule 40 PVC 0.010-slot Slotted Screen
GRAVEL PACK TYPE #2/16 Monterey Sand
GROUT TYPE/QUANTITY Neat Cement Grout / Medium Bentonite Chips
STATIC WATER LEVEL (FT BELOW TOC)
GROUND WATER ELEVATION (FT MSL)

PID (ppm)	BLOW COUNTS	RECOVERY (inches)	DEPTH (feet bgs)	U.S.C.S.	LITHOLOGIC DESCRIPTION	CONTACT DEPTH
					3" Asphalt cored (18" diameter)	0.2
					Hand augered to 5 feet bgs for utility clearance. ~0.5' of road base (Silty Sand-Gravel mixture)	0.7
				SP	1-4: SILTY SAND: Olive brown (2.5Y3/1); 60% fine to coarse, poorly graded, angular to subround sand; 30% micaceous silt; 10% clay, in "balls".	
			5			5.0
0.0/0.0	1,1, 3,4	20.4"/24"			5-7: CLAY: Very dark gray (2.5Y3/1); 95% moderately plastic clay; 5% micaceous silt; wet.	
0.0/0.0	8,8, 7,13	24"/24"		CH	7-8: Similar to above with plant and wood fragments.	
					8-9: Similar to above with Dark gray clay "balls"	
0.0/0.0	1,1, 3,4	24"/24"			9-9.6: Similar to above with layer of fine sand.	9.6
			10		9.6-11.2: Similar to above with transition to Dark grayish brown Silty Clay with worm casings.	
0.0/0.0	5,5, 6,9	18"/24"		CL ML	11.2-13: VERY SILTY CLAY: Light olive brown (2.5Y5/4); 60% moderately plastic clay; 30% micaceous silt; 10% fine to coarse, subangular to subround sand; <1% fine gravel; iron oxide mottling; wet; worm casings.	
0.0/0.0	3,5,7, 7,8	6"/24"			13-15: SImilar to above; wet to saturated in center.	
			15			15.0
0.0/0.0	3,5, 6,8	24"/24"			15-16.5: CLAYEY SAND: Dark olive brown (2.5Y3/3) to dark greenish gray (GLEY4/5GY); 70% fine to medium, subround sand; 20% stiff clay; 10% micaceous silt.	
0.1/0.0	11,13, 17,17	24"/24"			16.5-23: Similar to above with increasing fine sand and predominantly dark greenish gray in color. Similar to 15'-16.5'.	
0.0/0.0	3,5, 10,9	18"/24"		SP		
			20			
0.0/0.0	11,14, 11,13	20.4"/24"				
						23.0
0.4/0.0	7,10,5, 8,11	24"/24"			23-23.5: SILTY SAND: Olive brown (2.5Y4/3); 70% well graded, subangular to subround, fine sand; 30% micaceous silt; saturated.	
			25		23.5-23.7: Dark brown (10YR3/3) sandy clay layer.	
0.0/0.0	11,15, 17,22	24"/24"		SP	23.7-28: Similar to 23'-23.5' with some iron oxide mottling concentrated at bottom of section.	
0.0/0.0	NM	24"/24"				
						28.0
				SP		28.4
				SC	28-28.4: VERY SANDY CLAY: Light brownish gray (2.5Y6/2); 55% plastic clay; 30% fine to coarse, subangular to subround sand; 10% micaceous silt; 5%	
0.0/0.0	5,10, 11,11	24"/24"		SP		29.5
			30	SM		

Continued Next Page

WELL DIAGRAM:
- 4" PVC slip cap
- Concrete
- Annular Seal
- Borehole Diameter = 11"
- Neat Cement Grout
- 15 feet of 4" Sch 40 PVC Blank Riser
- Hydrated PureGold Medium Bentonite Chips
- #2/16 Monterey Sand Filter Pack
- 20 feet of 4" SCH 40 PVC 0.010-slot Slotted Screen with Threaded Couplings
- #2/16 Monterey Sand Filter Pack

SEALBEACH SEALBEACH.GPJ NEWGINT.GDT 10/24/07

CDM
111 Academy, Suite 150
Irvine, CA 92617
Phone: (949) 752-5452
Fax: (949) 725-3907

BORING/WELL CONSTRUCTION LOG

PROJECT NUMBER 50999-56254-6225.001.TK4.EQUIP **BORING/WELL NUMBER** AMW1

PROJECT NAME Naval Weapons Station-Seal Beach, Site 70 **DATE DRILLED** 9/5/07

Continued from Previous Page

PID (ppm)	BLOW COUNTS	RECOVERY (inches)	DEPTH (feet bgs)	U.S.C.S.	GRAPHIC LOG	LITHOLOGIC DESCRIPTION	CONTACT DEPTH	WELL DIAGRAM
				SP		subangular, fine gravel; saturated.		
				SC		28.4-29.5: Similar to 23.7'-28'.	31.0	
0.0/0.0	11,12, 15,17	24"/24"		SP		29.5-31: Similar to 28'-28.4', but heavilty bioturbated.		#2/16 Monterey Sand Filter Pack
				SM		31-32: Similar to 23.7'-28'.	32.0	
				SP		32-33: SImilar to 29.5'-31'.		
				SC			33.0	
0.0/0.0	4,7, 11,21	20.4"/24"		SP		33-34: Similar to 31'-32'.		
				SM			34.0	
				SP		34-34.2: Similar to above with fine to medium, subangular to subround gravel.	34.2	
			35	ML			35.1	Threaded SCH 40 PVC Bottom Cap
0.0/0.0	4,5, 7,11	24"/24"		SP		34.2-35.1: VERYSANDY SILT: Olive (5Y4/3); 60% micaceous silt; 35% well graded, subround, fine sand; <10% clay; wet to saturated.		
				SM		35.1-37: Similar to 33'-34' with iron oxide mottling.	37.0	Slough
						Total Depth of Boring = 36.5 feet bgs (with slough) Total Depth of Well = 35.1 feet bgs		
			40					
			45					
			50					
			55					
			60					

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CDM
111 Academy, Suite 150
Irvine, CA 92617
Phone: (949) 752-5452
Fax: (949) 725-3907

BORING/WELL CONSTRUCTION LOG

PROJECT NUMBER 50999-56254-6225.001.TK4.EQUIP
PROJECT NAME Naval Weapons Station-Seal Beach, Site 70
LOCATION Naval Weapons Station-Seal Beach
DRILLING METHOD CME 75 Hollow Stem Auger
SAMPLING METHOD 1.5' CA-Modified Split Spoon
GROUND SURFACE ELEVATION (FT MSL)
TOP OF CASING ELEVATION (FT MSL)
LOGGED BY Kristeen Bennett
REMARKS

BORING/WELL NUMBER AMW2
DATE DRILLED 9/6/07
CASING TYPE/DIAMETER 4" Schedule 40 PVC
SCREEN TYPE/SLOT 4" Schedule 40 PVC 0.010-slot Slotted Screen
GRAVEL PACK TYPE #2/16 Monterey Sand
GROUT TYPE/QUANTITY Neat Cement Grout / Medium Bentonite Chips
STATIC WATER LEVEL (FT BELOW TOC)
GROUND WATER ELEVATION (FT MSL)

PID (ppm)	BLOW COUNTS	RECOVERY (inches)	DEPTH (feet bgs)	U.S.C.S.	LITHOLOGIC DESCRIPTION	CONTACT DEPTH
					3" Asphalt cored (18" diameter) Hand augered to 5 feet bgs for utility clearance. ~4' of road base (Silty Sand-Gravel mixture)	0.2
				SP	4.3-5: SAND: Dark brown (10YR3/3); 80% fine to coarse, poorly graded, subangular to subround sand; 10% micaceous silt; 10% clay; moist.	4.3 5.0
0.0/0.0	1,3, 16,12	21.6"/24"	5		5-6: CLAY: Very dark gray (5Y3/1); 95% stiff clay; 5% micaceous silt; moist; worm casings.	
0.0/0.0	8,8, 8,9	24"/24"			6-6.8: Similar to above with change in color to Grayish brown (2.5Y5/2). 6.8-7: No Recovery.	7.0
0.0/0.0	1,1, 2,4	15.6"/24"		CH	7-9: Similar to above with change in color to Dark gray (2.5Y3/1). 9-9.2: Similar to 5.0'-6.0'. 9.2-10.6: Similar to 7.0'-9.0'.	
0.0/0.0	2,3, 3,7	18"/24"	10		11-13: Similar to above with change in color to Olive (5Y5/2) and no worm casings.	
0.0/0.0	10,2,4	2.4"/24"			13-15: No Recovery.	13.0
0.0/0.0	1,2, 5,9	24"/24"	15		15-21.2: CLAYEY SAND: Dark grayish brown (10YR4/2); 70% fine, well graded sand; 20% stiff clay; 10% micaceous silt; wet; iron oxide mottling; few worm casings.	15.0
0.0/0.0	9,14, --,7	24"/24"		SC		
0.0/0.0	1,4, 9,10	24"/24"	20		18.5-18.6: thin, fine gravel layer.	
0.0/0.0	12,18, 17,21	24"/24"			21.2-28.5: VERY CLAYEY SAND: Dark grayish brown (10YR4/2); 50% fine to medium, well graded subangular to subround sand; 30% moderately plastic clay; 20% micaceous silt; saturated.	21.2
0.0/0.0	1,2, 4,11	24"/24"				
0.0/0.0	11,15, 17,22	24"/24"	25	SC		
0.0/0.0	14,19, 19,19	24"/24"				
						28.5
				SM	28.5-29.2: VERY SILTY SAND: Dark grayish brown (2.5Y4/2); 55% fine, well graded, subangular to subround sand; 35% micaceous silt; 10% clay; saturated.	29.2
0.0/0.0	2,11, 7,12	24"/24"		ML		29.7
			30			

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WELL DIAGRAM
- 4" PVC slip cap
- Concrete Annular Seal
- Neat Cement Grout
- 15 feet of 4" Sch 40 PVC Blank Riser
- Borehole Diameter = 11"
- Hydrated PureGold Medium Bentonite Chips
- #2/16 Monterey Sand Filter Pack
- 20 feet of 4" SCH 40 PVC 0.010-slot Slotted Screen with Threaded Couplings
- #2/16 Monterey Sand Filter Pack

SEALBEACH SEALBEACH.GPJ NEWGINT.GDT 10/24/07

CDM
111 Academy, Suite 150
Irvine, CA 92617
Phone: (949) 752-5452
Fax: (949) 725-3907

BORING/WELL CONSTRUCTION LOG

PROJECT NUMBER 50999-56254-6225.001.TK4.EQUIP **BORING/WELL NUMBER** AMW2

PROJECT NAME Naval Weapons Station-Seal Beach, Site 70 **DATE DRILLED** 9/6/07

Continued from Previous Page

PID (ppm)	BLOW COUNTS	RECOVERY (inches)	DEPTH (feet bgs)	U.S.C.S.	GRAPHIC LOG	LITHOLOGIC DESCRIPTION	CONTACT DEPTH	WELL DIAGRAM
				CL		29.2-29.7: SANDY SILT: Olive (5Y4/3); 70% micaceous silt; 15% fine, well graded sand; 15% plastic clay; saturated.	30.5	
0.0/0.0	7,12, 15,12	20.4"/24"		ML		29.7-30.5: CLAY: Olive (5Y4/3); 90% moderately plastic clay; 10% micaceous silt; greenish gray (reduced iron?) and iron oxide mottling.	32.0	#2/16 Monterey Sand Filter Pack
				CL			33.0	
0.0/0.0	4,11, 12,12	24"/24"		SM		30.5-32: SANDY SILT: Olive brown (2.5Y4/3); 60% micaceous silt; 25% fine to medium, well graded sand; 15% plastic clay; saturated	34.2	
0.0/0.0	3,5, 7,10	24"/24"	35	CL		32-33: Similar to 29.7'-30.5'. 33-34.2: CLAYEY SILTY SAND: Olive brown (2.5Y4/3); 65% fine to medium, well graded, subangular to subround sand; 20% micaceous silt; 15% plastic clay; organic debris; saturated.		Threaded SCH 40 PVC Bottom Cap
						34.2-37: Similar to 29.7'-30.5'.	37.0	Slough
			40			Total Depth of Boring = 36 feet bgs (with slough) Total Depth of Well = 34.95 feet bgs		
			45					
			50					
			55					
			60					

SEALBEACH SEALBEACH.GPJ NEWGINT.GDT 10/24/07

CDM
111 Academy, Suite 150
Irvine, CA 92617
Phone: (949) 752-5452
Fax: (949) 725-3907

BORING/WELL CONSTRUCTION LOG

PROJECT NUMBER 50999-56254-6225.001.TK4.EQUIP
BORING/WELL NUMBER AMW3
PROJECT NAME Naval Weapons Station-Seal Beach, Site 70
DATE DRILLED 9/17/07
LOCATION Naval Weapons Station-Seal Beach
CASING TYPE/DIAMETER 1.6" Solinst CMT Multiport HDPE Tubing
DRILLING METHOD Geoprobe 6620DT Direct Push / Hollow Stem Auger
SCREEN TYPE/SLOT 3 0.38" Holes covered by Stainless Steel Mesh
SAMPLING METHOD 4' Split Spoon-Continuous Core
GRAVEL PACK TYPE #2/16 Monterey Sand
GROUND SURFACE ELEVATION (FT MSL)
GROUT TYPE/QUANTITY Neat Cement Grout / Medium Bentonite Chips
TOP OF CASING ELEVATION (FT MSL)
STATIC WATER LEVEL (FT BELOW TOC)
LOGGED BY Kristeen Bennett
GROUND WATER ELEVATION (FT MSL)
REMARKS Port designation are labeled counterclockwise (i.e. Port 1 is still Port 1, Port 2 is Port 6, Port 3 is Port 5, and Port 4 is Port 4)

PID (ppm)	BLOW COUNTS	RECOVERY (inches)	DEPTH (feet bgs)	U.S.C.S.	GRAPHIC LOG	LITHOLOGIC DESCRIPTION	CONTACT DEPTH
						0-5: No Recovery. Hand augered to 5 feet bgs for utility clearance	
0.0 0.0 0.0 0.0	NM	21"/36"	5			5-8: CLAY: Black (5Y2.5/1) to Very dark grayish brown (2.5Y3/2); 90% stiff clay; 10% micaceous silt; moist.	5.0
0.0 0.0 0.0 0.0	NM	38"/48"	10	CH		8-13.5: Similar to above with color change at sample base to Olive brown (2.5Y5/3) and with increasing silt.	
0.0 0.0 0.0 0.0	NM	48"/48"	15	CL ML		13.5-15.5: VERY SILTY CLAY: Grayish brown (2.5Y5/2) to brown (10YR4/3); 55% moderately plastic clay; 35% micaceous silt; 10% fine, subround, well graded sand; moist.	13.5 15.5
0.0 0.0 0.0 0.0	NM	48"/48"		CL		15.5-20: VERY SANDY CLAY: Dark brown (10YR3/3) to olive brown (2.5Y4/3); 55% stiff clay; 40% fine to medium, subround, well sorted sand; 5% micaceous silt; dry; iron oxide mottling throughout.	
0.0 0.0 0.0 0.0	NM	43"/48"	20			20.5-24: SILTY SAND: Olive brown (2.5Y4/3); 65% fine to medium, subangular to subround, well graded sand; 30% micaceous silt; 5% plastic clay; saturated; some iron oxide mottling.	20.0
0.0 0.0 0.0 0.0	NM	47"/48"	25	SM		24-28.5: Similar to above.	
						27-27.2: Light brownish gray clay layer.	27.2
0.0 0.2 0.0	NM	36"/36"	30	ML		28-31: VERY CLAYEY SILT: Grayish brown (2.5Y5/2) to olive brown (2.5Y4/3); 60% micaceous silt; 35% plastic clay; 5% fine to coarse, subangular to subround, poorly	28.5

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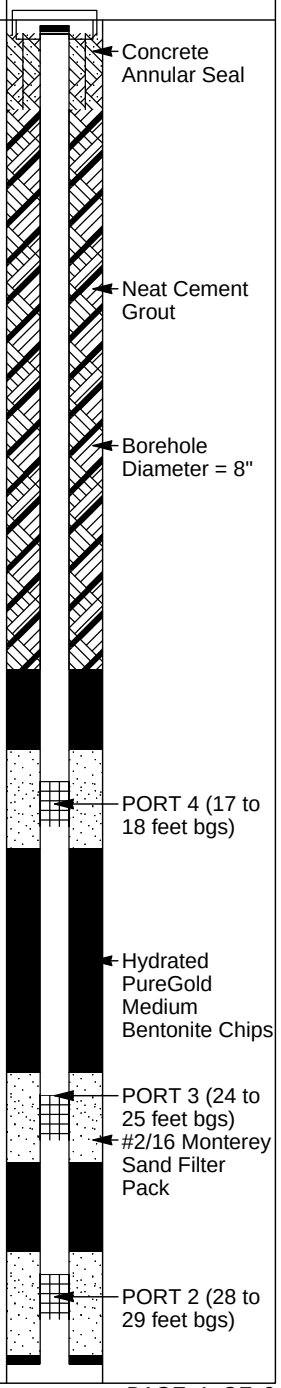

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CDM
111 Academy, Suite 150
Irvine, CA 92617
Phone: (949) 752-5452
Fax: (949) 725-3907

BORING/WELL CONSTRUCTION LOG

PROJECT NUMBER 50999-56254-6225.001.TK4.EQUIP **BORING/WELL NUMBER** AMW3

PROJECT NAME Naval Weapons Station-Seal Beach, Site 70 **DATE DRILLED** 9/17/07

Continued from Previous Page

PID (ppm)	BLOW COUNTS	RECOVERY (inches)	DEPTH (feet bgs)	U.S.C.S.	GRAPHIC LOG	LITHOLOGIC DESCRIPTION	CONTACT DEPTH	WELL DIAGRAM
						graded sand; saturated.	31.0	Hydrated PureGold Medium Bentonite Chips
0.0	NM	24"/24"		ML		31-31.5: SANDY SILT: Olive gray (5Y4/2); 60%	31.5	
0.0				ML		micaceous silt; 30% fine, subround, well graded sand; 10% plastic clay; saturated.	32.5	
0.0						31.5-32.5: Similar to 28'-31'.		
0.6	NM	36"/36"		ML		32.5-34: Similar to 31'-31.5'.		PORT 1 (33 to 34 feet bgs)
0.2							34.0	
0.0				ML		34-35: Similar to 28'-31'.		#2/16 Monterey Sand Filter Pack
0.0			35				35.0	
				CL ML		35-36: SILTY CLAY: Olive brown (2.5Y4/3); 80% moderately plastic clay; 20% micaceous silt; wet.	36.0	
						Total Depth of Boring = 36.5 feet bgs Total Depth of Well = 35 feet bgs		
			40					
			45					
			50					
			55					
			60					

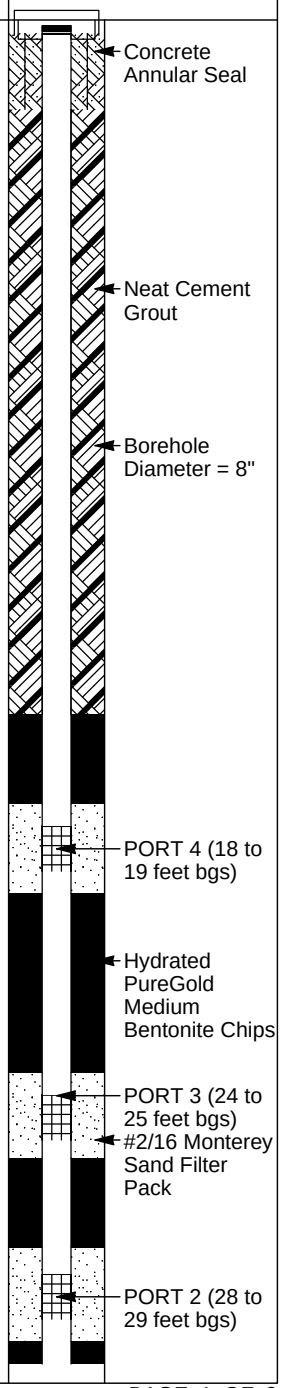
SEALBEACH SEALBEACH.GPJ NEWGINT.GDT 10/24/07

CDM
111 Academy, Suite 150
Irvine, CA 92617
Phone: (949) 752-5452
Fax: (949) 725-3907

BORING/WELL CONSTRUCTION LOG

PROJECT NUMBER 50999-56254-6225.001.TK4.EQUIP
BORING/WELL NUMBER AMW4
PROJECT NAME Naval Weapons Station-Seal Beach, Site 70
DATE DRILLED 9/17/07
LOCATION Naval Weapons Station-Seal Beach
CASING TYPE/DIAMETER 1.6" Solinst CMT Multiport HDPE Tubing
DRILLING METHOD Geoprobe 6620DT Direct Push / Hollow Stem Auger
SCREEN TYPE/SLOT 3 0.38" Holes covered by Stainless Steel Mesh
SAMPLING METHOD 4' Split Spoon-Continuous Core
GRAVEL PACK TYPE #2/16 Monterey Sand
GROUND SURFACE ELEVATION (FT MSL)
GROUT TYPE/QUANTITY Neat Cement Grout / Medium Bentonite Chips
TOP OF CASING ELEVATION (FT MSL)
STATIC WATER LEVEL (FT BELOW TOC)
LOGGED BY Kristeen Bennett
GROUND WATER ELEVATION (FT MSL)
REMARKS Port designation are labeled counterclockwise (i.e. Port 1 is still Port 1, Port 2 is Port 6, Port 3 is Port 5, and Port 4 is Port 4)

PID (ppm)	BLOW COUNTS	RECOVERY (inches)	DEPTH (feet bgs)	U.S.C.S.	GRAPHIC LOG	LITHOLOGIC DESCRIPTION	CONTACT DEPTH
						0-5: No Recovery. Hand augered to 5 feet bgs for utility clearance.	
0.0 0.0 0.0	NM	21"/36"	5	CL		5-8: SILTY CLAY: Dark olive gray (5Y3/2); 80% moderately plastic clay; 15% micaceous silt; 5% fine, subround, well graded sand; moist; worm casings.	5.0
0.0 0.0 0.0 0.0	NM	32"/48"				8-10: Similar to above with change in color to Olive gray (5Y4/2).	
0.0 0.0 0.0 0.0	NM	33"/48"	10 15	CL		10-11.5: SANDY CLAY: Olive gray (5Y5/2); 70% plastic clay; 25% fine, subround, well graded sand; 5% micaceous silt; saturated. 11.5-13.5: SImilar to 8'-10'. 13.5-16: VERY SANDY CLAY: Olive brown (2.5Y4/4); 50% stiff clay; 40% fine to medium, subangular to subround, well sorted sand; 10% micaceous silt; moist; iron oxide mottling.	10.0
NR	NM	43"/48"		SC		16-20: VERY CLAYEY SAND: Dark yellowish brown (10YR4/4); 60% fine to medium, subangular to subround, well sorted sand; 35% stiff clay; 10% micaceous silt; moist.	16.0
NR	NM	48"/48"	20			20-21: No Recovery.	20.0
				SC		21-22.5: Similar to 16'-20' with increasing sand and change in color to Olive gray (5Y4/2); iron oxide mottling concentrated at bottom of section.	21.0
				CL ML		22.5-24: SILTY CLAY: Olive (5Y4/4) to light gray (5Y7/2); 60% platy, moderately plastic, banded (see colors above) clay; 30% micaceous silt; fine to medium grained, well sorted, subangular to subround sand; wet.	22.5
0.0 0.2 0.0 0.0	NM	48"/48"	25	SM		24-27: SILTY SAND: Olive (5Y4/3); 70% fine to medium, subangular to subround, well sorted sand; 30% micaceous silt; saturated.	24.0 27.0
NR	NM	24"/24"		CL		27-28: VERY CLAYEY SILT: Pale olive (5Y6/3); 50% micaceous silt; 40% plastic clay; 10% fine, subround, well sorted sand; wet. 28-29: Similar to 27'-28' with some iron oxide mottling; saturated.	29.6
			30			*Continued Next Page*	



SEALBEACH SEALBEACH.GPJ NEWGINT.GDT 10/24/07

CDM
111 Academy, Suite 150
Irvine, CA 92617
Phone: (949) 752-5452
Fax: (949) 725-3907

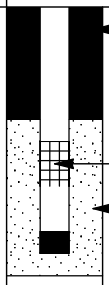
BORING/WELL CONSTRUCTION LOG

PROJECT NUMBER 50999-56254-6225.001.TK4.EQUIP **BORING/WELL NUMBER** AMW4

PROJECT NAME Naval Weapons Station-Seal Beach, Site 70 **DATE DRILLED** 9/17/07

Continued from Previous Page

PID (ppm)	BLOW COUNTS	RECOVERY (inches)	DEPTH (feet bgs)	U.S.C.S.	GRAPHIC LOG	LITHOLOGIC DESCRIPTION	CONTACT DEPTH	WELL DIAGRAM
NR	NM	29"/36"		ML		29-32: Similar to 27'-28' with laminar bedding. 29.5-29.6: Fine to medium gravel layer.		
							32.0	
				CL		32-32.5: SILTY CLAY: Olive gray (5Y5/2); 80% moderately plastic clay; 20% micaceous silt; wet.	32.5	
NR	NM	36"/36"		SM		32.5-34: SILTY SAND: Olive (5Y5/3); 60% fine to medium, subround, well sorted sand; 30% micaceous silt; 10% plastic clay; saturated.	34.0	
			35	CL ML		34-36: Similar to 27'-28'.		
							36.0	
						Total Depth of Boring = 36 feet bgs Total Depth of Well = 35 feet bgs		
			40					
			45					
			50					
			55					
			60					



Hydrated PureGold Medium Bentonite Chips

PORT 1 (33 to 34 feet bgs)

#2/16 Monterey Sand Filter Pack

SEALBEACH SEALBEACH.GPJ NEWGINT.GDT 10/24/07

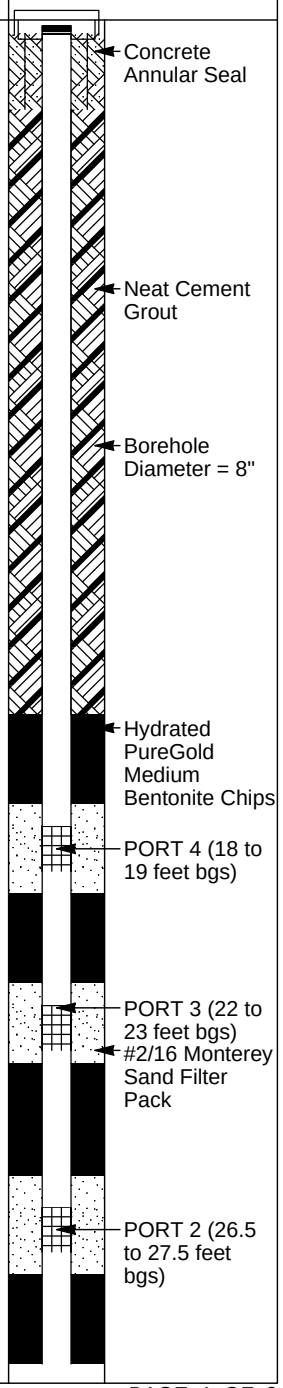
CDM
111 Academy, Suite 150
Irvine, CA 92617
Phone: (949) 752-5452
Fax: (949) 725-3907

BORING/WELL CONSTRUCTION LOG

PROJECT NUMBER 50999-56254-6225.001.TK4.EQUIP
BORING/WELL NUMBER AMW5
PROJECT NAME Naval Weapons Station-Seal Beach, Site 70
DATE DRILLED 9/17/07
LOCATION Naval Weapons Station-Seal Beach
CASING TYPE/DIAMETER 1.6" Solinst CMT Multiport HDPE Tubing
DRILLING METHOD Geoprobe 6620DT Direct Push / Hollow Stem Auger
SCREEN TYPE/SLOT 3 0.38" Holes covered by Stainless Steel Mesh
SAMPLING METHOD 4' Split Spoon-Continuous Core
GRAVEL PACK TYPE #2/16 Monterey Sand
GROUND SURFACE ELEVATION (FT MSL)
GROUT TYPE/QUANTITY Neat Cement Grout / Medium Bentonite Chips
TOP OF CASING ELEVATION (FT MSL)
STATIC WATER LEVEL (FT BELOW TOC)
LOGGED BY Kristeen Bennett
GROUND WATER ELEVATION (FT MSL)
REMARKS Port designation are labeled counterclockwise (i.e. Port 1 is still Port 1, Port 2 is Port 6, Port 3 is Port 5, and Port 4 is Port 4)

PID (ppm)	BLOW COUNTS	RECOVERY (inches)	DEPTH (feet bgs)	U.S.C.S.	GRAPHIC LOG	LITHOLOGIC DESCRIPTION	CONTACT DEPTH
						0-8: No Recovery. Hand augered to 8 feet bgs for utility clearance.	
9.7 9.2 3.7 2.8	NM	30"/48"		CL		8-12: SILTY CLAY: Dark olive brown (2.5Y3/2.5); 85% moderately plastic clay; 15% micaceous silt; dry.	8.0
0.2 0.0 0.0 0.0	NM	48"/48"		CL		12-13: Similar to above with worm casings. 13-16: SANDY CLAY: Dark olive brown (2.5Y3/3) to dark yellowish brown (10YR4/6); 70% moderately plastic to stiff clay; 20% fine to medium, subround, well sorted sand; 10% micaceous silt; dry; iron oxide mottling.	13.0
0.0 0.0 0.0 0.0	NM	48"/48"		CL		16-18.5: Similar to above with increasing sands. 18.5-19: Similar to above with decreasing sand and change in color to Dark olive gray (5Y3/2); dry. 19-20: Similar to 16'-18.5'.	20.0
0.0 0.4 0.0	NM	36"/36"		SC		20-22.5: CLAYEY SAND: Olive brown (2.5Y4/4); 60% fine to medium, subangular to subround, well graded sand; 30% stiff clay; 10% micaceous silt; moist; iron oxide mottling.	22.5
0.0 0.0 0.0 0.0	NM	36"/36"		SM CL ML SM CL ML SM CL ML ML CL		22.5-23: CLAYEY SILTY SAND: Olive brown (2.5Y4/3); 60% fine to medium, subround, well sorted sand; 25% micaceous silt; 15% moderately plastic clay; wet. 23-24: SILTY CLAY: Pale olive (5Y6/3) to light gray (5Y7/2); 70% moderately plastic clay; 25% micaceous silt; 5% fine to medium, subangular to subround, well graded sand; wet. 24-25.5: SILTY SAND: Olive (5Y4/3); 70% fine to medium, subangular to subround, well graded sand; 30% micaceous silt; wet. 25.5-26: Similar to 23'-24'. 26-27.5: Similar to 24'-25.5'. 27.5-28: Similar to 23'-24'. 28-29: VERY SANDY SILT: Olive (5Y4/3); 60% micaceous	23.0 24.0 25.5 26.0 27.5 28.0 29.0 30.0

Continued Next Page



SEALBEACH SEALBEACH.GPJ NEWGINT.GDT 10/24/07

CDM
111 Academy, Suite 150
Irvine, CA 92617
Phone: (949) 752-5452
Fax: (949) 725-3907

BORING/WELL CONSTRUCTION LOG

PROJECT NUMBER 50999-56254-6225.001.TK4.EQUIP **BORING/WELL NUMBER** AMW5

PROJECT NAME Naval Weapons Station-Seal Beach, Site 70 **DATE DRILLED** 9/17/07

Continued from Previous Page

PID (ppm)	BLOW COUNTS	RECOVERY (inches)	DEPTH (feet bgs)	U.S.C.S.	GRAPHIC LOG	LITHOLOGIC DESCRIPTION	CONTACT DEPTH	WELL DIAGRAM
				ML		silt; 35% fine, subround, well graded sand; 5% plastic clay; wet.	31.0	Hydrated PureGold Medium Bentonite Chips
				ML		29-30: SILTY CLAY: Light olive brown (2.5Y5/3); 85% moderately plastic clay; 15% micaceous silt; moist. 30-31: Similar to 28'-29'.		
				ML		31-32: CLAYEY SILT: Grayish brown (2.5Y5/2); 60% micaceous silt; 30% moderately plastic clay; 10% fine, subround, well graded sand; wet. 32-33.5: Similar to above.	33.5	
			35			33.5-35: Similar to 28'-29'.	35.0	PORT 1 (33 to 34 feet bgs)
				CL ML		35-36: SILTY CLAY: Olive gray (5Y5/2); 75% moderately plastic clay; 25% micaceous silt; wet.	36.0	#2/16 Monterey Sand Filter Pack
						Total Depth of Boring = 36.4 feet bgs Total Depth of Well = 35 feet bgs		
			40					
			45					
			50					
			55					
			60					

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111 Academy, Suite 150
Irvine, CA 92617
Phone: (949) 752-5452
Fax: (949) 725-3907

BORING/WELL CONSTRUCTION LOG

PROJECT NUMBER 50999-56254-6225.001.TK4.EQUIP
PROJECT NAME Naval Weapons Station-Seal Beach, Site 70
LOCATION Naval Weapons Station-Seal Beach
DRILLING METHOD CME 75 Hollow Stem Auger
SAMPLING METHOD 4' Split Spoon-Continuous Core
GROUND SURFACE ELEVATION (FT MSL)
TOP OF CASING ELEVATION (FT MSL)
LOGGED BY Kristeen Bennett
REMARKS

BORING/WELL NUMBER AMW6
DATE DRILLED 9/7/07
CASING TYPE/DIAMETER 4" Schedule 40 PVC
SCREEN TYPE/SLOT 4" Schedule 40 PVC 0.010-slot Slotted Screen
GRAVEL PACK TYPE #2/16 Monterey Sand
GROUT TYPE/QUANTITY Neat Cement Grout / Medium Bentonite Chips
STATIC WATER LEVEL (FT BELOW TOC)
GROUND WATER ELEVATION (FT MSL)

PID (ppm)	BLOW COUNTS	RECOVERY (inches)	DEPTH (feet bgs)	U.S.C.S.	LITHOLOGIC DESCRIPTION	CONTACT DEPTH
			0		3" Asphalt cored (18" diameter) Hand augered to 5 feet bgs for utility clearance. ~5' of road base (Silty Sand-Gravel mixture)	0.3
0.0/0.0	NM	46"/60"	5		5.2-10: CLAY: Very dark grayish brown (2.5Y3/2); 90% stiff clay; 10% fine to medium, well graded, subangular sand; iron oxide mottling; thin, laminar bedding. 7.5-9.0: Similar to above with some bioturbation and worm casings.	5.2 9.0
0.0/0.0	NM	58"/60"	10	CL	10-13: Similar to above with change in color to Olive gray (5Y4/2). 13-15.5: Similar to above with change in color to Dark yellowish brown (10YR3/4).	
11.3 20.9 46.4	NM	58"/60"	15	CL	15.5-17: VERY SANDY CLAY: Dark yellowish brown (10YR3/4); 60% stiff clay: 35% fine to medium, well graded, subangular sand; 5% micaceous silt; wet; few worm casings; iron oxide mottling. 17-19: Similar to above with no mottling and change in color to Olive brown (2.5Y4/3). 19-19.25: Similar to above with more plastic clay and color change to Light olive brown (2.5Y5/2).	15.5
5.7 19.4	NM	32"/60"	20		19.25-20: Similar to 15.5'-17' with abundant bioturbation. 20-23: SAND: Dark yellowish brown (10YR4/6); 80% fine to medium, well graded, subround sand; 10% micaceous silt; 10% clay; wet; iron oxide mottling throughout. 23-26: Similar to above with change in color to Dark grayish brown (2.5Y4/2); wet.	20.0
22.7 10.4 12.3	NM	48"/60"	25	SW	26-29: Similar to above with increasing silt and fine sand.	
			30		29-33.5: SANDY SILT: Olive gray (5Y5/2); 70% micaceous silt; 20% fine sand; 10% clay; laminar bedding;	29.0

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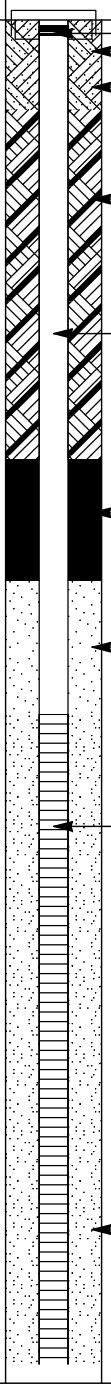
WELL DIAGRAM



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CDM
111 Academy, Suite 150
Irvine, CA 92617
Phone: (949) 752-5452
Fax: (949) 725-3907

BORING/WELL CONSTRUCTION LOG

PROJECT NUMBER 50999-56254-6225.001.TK4.EQUIP **BORING/WELL NUMBER** AMW6

PROJECT NAME Naval Weapons Station-Seal Beach, Site 70 **DATE DRILLED** 9/7/07

Continued from Previous Page

PID (ppm)	BLOW COUNTS	RECOVERY (inches)	DEPTH (feet bgs)	U.S.C.S.	GRAPHIC LOG	LITHOLOGIC DESCRIPTION	CONTACT DEPTH	WELL DIAGRAM
3.4 2.1 0.9	NM	44"/60"		ML		wet. 33.5-35: Similar to above with iron oxide mottling.	35.0	#2/16 Monterey Sand Filter Pack
			35					Threaded SCH 40 PVC Bottom Cap
						Total Depth of Boring = 35 feet bgs (with slough) Total Depth of Well = 35.5 feet bgs		
			40					
			45					
			50					
			55					
			60					

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111 Academy, Suite 150
Irvine, CA 92617
Phone: (949) 752-5452
Fax: (949) 725-3907

BORING/WELL CONSTRUCTION LOG

PROJECT NUMBER 50999-56254-6225.001.TK4.EQUIP
PROJECT NAME Naval Weapons Station-Seal Beach, Site 70
LOCATION Naval Weapons Station-Seal Beach
DRILLING METHOD CME 75 Hollow Stem Auger
SAMPLING METHOD 4' Split Spoon-Continuous Core
GROUND SURFACE ELEVATION (FT MSL)
TOP OF CASING ELEVATION (FT MSL)
LOGGED BY Kristeen Bennett
REMARKS

BORING/WELL NUMBER PMW1
DATE DRILLED 9/13/07
CASING TYPE/DIAMETER 4" Schedule 40 PVC
SCREEN TYPE/SLOT 4" Schedule 40 PVC 0.010-slot Slotted Screen
GRAVEL PACK TYPE #2/16 Monterey Sand
GROUT TYPE/QUANTITY Neat Cement Grout / Medium Bentonite Chips
STATIC WATER LEVEL (FT BELOW TOC)
GROUND WATER ELEVATION (FT MSL)

PID (ppm)	BLOW COUNTS	RECOVERY (inches)	DEPTH (feet bgs)	U.S.C.S.	LITHOLOGIC DESCRIPTION	CONTACT DEPTH
0.0					3" Asphalt cored (18" diameter) Hand augered to 5 feet bgs for utility clearance. ~4' of road base (Silty Sand-Gravel mixture)	0.2
						4.0
0.0 0.0 0.0 0.0	NM	34"/60"	5		4-9: CLAY: Very dark gray (10YR3/1); 90% moderately plastic clay; 10% micaceous silt; wet.	
0.0 0.0 0.0 0.0	NM	58"/60"	10	CL	9-10: Similar to above with change in color to Dark grayish brown (2.5Y4/2), trace (<5%) fine to medium sand, and organic material (grass); wet. 10-14: Similar to above with decreasing sand.	
0.0 0.0 0.0 0.0	NM	38"/60"	15		14-15.5: Similar to above with change in color to Dark gray (2.5Y4/1); wet 15.5-17: Similar to above with "balls" of yellowish red sand.	
						17.0
				CL	17-20: SANDY CLAY: Dark grayish brown (10YR4/2); 60% moderately plastic clay; 30% fine, subangular, well graded sand; 10% micaceous silt; iron oxide mottling in sand seams; wet.	
						20.0
0.4 0.4 0.6 0.7	NM	52"/60"	20	SC	20-23.5: VERY CLAYEY SAND: Dark grayish brown (10YR4/2) to brown (10YR4/3); 50% fine, subround, well graded sand; 40% plastic clay; 10% micaceous silt; wet.	
					23.5-25: Similar to above with change in color to Olive (5Y4/3) and with pale yellow (5Y8/3) clay seams throughout; wet.	
						25.0
1.0 0.8 0.7 1.0	NM	51"/60"	25	SM	25-30: SILTY SAND: Olive gray (5Y4.5/2); 65% fine to medium, subangular to subround, well graded sand; 30% micaceous silt; 5% plastic clay; saturated	
			30			

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WELL DIAGRAM

- 4" PVC slip cap
- Concrete
- Annular Seal Borehole Diameter = 11"
- Neat Cement Grout
- 15 feet of 4" Sch 40 PVC Blank Riser
- Hydrated PureGold Medium Bentonite Chips
- #2/16 Monterey Sand Filter Pack
- 20 feet of 4" SCH 40 PVC 0.010-slot Slotted Screen with Threaded Couplings
- #2/16 Monterey Sand Filter Pack

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CDM
111 Academy, Suite 150
Irvine, CA 92617
Phone: (949) 752-5452
Fax: (949) 725-3907

BORING/WELL CONSTRUCTION LOG

PROJECT NUMBER 50999-56254-6225.001.TK4.EQUIP **BORING/WELL NUMBER** PMW1

PROJECT NAME Naval Weapons Station-Seal Beach, Site 70 **DATE DRILLED** 9/13/07

Continued from Previous Page

PID (ppm)	BLOW COUNTS	RECOVERY (inches)	DEPTH (feet bgs)	U.S.C.S.	GRAPHIC LOG	LITHOLOGIC DESCRIPTION	CONTACT DEPTH	WELL DIAGRAM
0.0 0.2 6.8 4.7	NM	60"/60"				30-32: Similar to above with increasing silt.		#2/16 Monterey Sand Filter Pack
				CL ML		32-34: SILTY CLAY: Olive brown (2.5Y4/4) to light olive brown (2.5Y5/4); 70% stiff clay; 30% micaceous silt; wet; iron oxde mottling throughout.	32.0 34.0	
				ML		34-35: SILT: Grayish brown (2.5Y5/2); 85% micaceous silt; 10% plastic clay; 5% fine, subround sand; wet.	35.0	Threaded SCH 40 PVC Bottom Cap
			35			Total Depth of Boring = 35.3 feet bgs Total Depth of Well = 35.3 feet bgs		
			40					
			45					
			50					
			55					
			60					

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CDM
111 Academy, Suite 150
Irvine, CA 92617
Phone: (949) 752-5452
Fax: (949) 725-3907

BORING/WELL CONSTRUCTION LOG

PROJECT NUMBER 50999-56254-6225.001.TK4.EQUIP
PROJECT NAME Naval Weapons Station-Seal Beach, Site 70
LOCATION Naval Weapons Station-Seal Beach
DRILLING METHOD CME 75 Hollow Stem Auger
SAMPLING METHOD 4' Split Spoon-Continuous Core
GROUND SURFACE ELEVATION (FT MSL)
TOP OF CASING ELEVATION (FT MSL)
LOGGED BY Kristeen Bennett
REMARKS

BORING/WELL NUMBER PMW9
DATE DRILLED 9/12/07
CASING TYPE/DIAMETER 4" Schedule 40 PVC
SCREEN TYPE/SLOT 4" Schedule 40 PVC 0.010-slot Slotted Screen
GRAVEL PACK TYPE #2/16 Monterey Sand
GROUT TYPE/QUANTITY Neat Cement Grout / Medium Bentonite Chips
STATIC WATER LEVEL (FT BELOW TOC)
GROUND WATER ELEVATION (FT MSL)

PID (ppm)	BLOW COUNTS	RECOVERY (inches)	DEPTH (feet bgs)	U.S.C.S.	GRAPHIC LOG	LITHOLOGIC DESCRIPTION	CONTACT DEPTH	WELL DIAGRAM
						3" Asphalt cored (18" diameter) Hand augered to 5 feet bgs for utility clearance. ~4' of road base (Silty Sand-Gravel mixture)	0.3	4" PVC slip cap Concrete Annular Seal
							4.0	Neat Cement Grout
0.0 0.0 0.0 0.0	NM	36"/60"	5	CL		4-14.5: CLAY: Black (2.5Y2/1) to dark grayish brown (2.5Y3/2); 90% moderately plastic clay; 10% fine to medium, subangular, well graded sand; light gray clay "balls"; moist.		15 feet of 4" Sch 40 PVC Blank Riser
0.0 0.0 0.0 0.0	NM	38"/60"	10					Borehole Diameter = 11" Hydrated PureGold Medium Bentonite Chips
							14.5	
0.0 0.0 0.1 0.1	NM	19"/60"	15			14.5-15: SANDY CLAY: Olive brown (2.5Y4/5); 60% moderately plastic clay; 30% fine, subround, well graded sand; 10% micaceous silt; iron oxide mottling; moist. 15-18.5: No Recovery.		#2/16 Monterey Sand Filter Pack
							18.5	
0.1 0.0 0.5 0.4	NM	11"/60"	20			18.5-19.5: Similar to 14.5'-15.5'. 19.5-20: Similar to above with change in color to Olive gray (5Y5/2) with increasing sands and decreasing iron oxide mottling. 20-24: No Recovery.		20 feet of 4" SCH 40 PVC 0.010-slot Slotted Screen with Threaded Couplings
							24.0	
0.8 1.4 1.7 0.7	NM	18"/60"	25			24-25: Similar to above with change in color to Olive brown (2.5Y4/4); saturated. 25-28: No Recovery.	25.0	#2/16 Monterey Sand Filter Pack
							28.0	
				SM		28-29: SILTY SAND: Olive brown (2.5Y4/2); 65% fine to medium, subangular to subround, well graded sand; 25% micaceous silt; 10% clay; saturated.	29.0	
			30	GC			30.0	

Continued Next Page

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CDM
111 Academy, Suite 150
Irvine, CA 92617
Phone: (949) 752-5452
Fax: (949) 725-3907

BORING/WELL CONSTRUCTION LOG

PROJECT NUMBER 50999-56254-6225.001.TK4.EQUIP **BORING/WELL NUMBER** PMW9

PROJECT NAME Naval Weapons Station-Seal Beach, Site 70 **DATE DRILLED** 9/12/07

Continued from Previous Page

PID (ppm)	BLOW COUNTS	RECOVERY (inches)	DEPTH (feet bgs)	U.S.C.S.	GRAPHIC LOG	LITHOLOGIC DESCRIPTION	CONTACT DEPTH	WELL DIAGRAM
46.5 9.6 9.9 1.8	NM	38"/60"	35	ML GC CL ML		29-30: GRAVELLY CLAY: Light yellowish brown (2.5Y6/3); 60% plastic clay; 30% fine to coarse, subangular gravel; 10% micaceous silt; saturated. 30-32: No Recovery. 32-32.5: VERY SANDY SILT: Light olive brown (2.5Y5/3); 50% micaceous silt; 35% fine, subround, well graded sand; 15% plastic clay; saturated. 32.5-33: Similar to 29'-30'. 33-35: GRAVELLY SILTY CLAY: Light olive brown (2.5Y5/3); 60% moderately plastic clay; 25% micaceous silt; 15% fine to medium, subangular to subround gravel; wet. Total Depth of Boring = 35.5 feet bgs (with slough) Total Depth of Well = 34.8 feet bgs	32.0 32.5 33.0 35.0	#2/16 Monterey Sand Filter Pack Threaded SCH 40 PVC Bottom Cap

SEALBEACH SEALBEACH.GPJ NEWGINT.GDT 10/24/07

Appendix E.3
Phase II Well Logs

CDM
111 Academy, Suite 150
Irvine, CA 92617
Phone: (949) 752-5452
Fax: (949) 725-3907

BORING/WELL CONSTRUCTION LOG

PROJECT NUMBER 50999-56254-6225.001.TK4.EQUIP
PROJECT NAME Naval Weapons Station-Seal Beach, Site 70
LOCATION Naval Weapons Station-Seal Beach
DRILLING METHOD CME 75 Hollow Stem Auger
SAMPLING METHOD 5' CA-Modified Split Spoon
GROUND SURFACE ELEVATION (FT MSL)
TOP OF CASING ELEVATION (FT MSL)
LOGGED BY Kristeen Bennett
REMARKS

BORING/WELL NUMBER PIW1
DATE DRILLED 3/26/08
CASING TYPE/DIAMETER 4" Schedule 40 PVC
SCREEN TYPE/SLOT 4" PVC 0.010 Slot
GRAVEL PACK TYPE #2/16 Lapis Lustre Sand
GROUT TYPE/QUANTITY Neat Cement Grout / Medium Bentonite Chips
STATIC WATER LEVEL (FT BELOW TOC)
GROUND WATER ELEVATION (FT MSL)

PID (ppm)	RECOVERY (inches)	DEPTH (feet bgs)	U.S.C.S.	LITHOLOGIC DESCRIPTION	CONTACT DEPTH
				3" Cored asphalt (diameter 18")	
			SM	0.2-3: SLIGHTLY CLAYEY SILTY SAND: Olive-brown (2.5YR4/4); fine to coarse, subangular to subrounded, poorly graded sand; soft; medium plasticity silt; medium stiff, low plasticity, very dark grayish brown clay balls; moist.	0.2
			SC	3-4: SANDY CLAY: Similar to clay balls above; very dark grayish-brown (2.5YR3/2); fine to coarse, subangular to subrounded, poorly gradded sand; trace silt; moist.	3.0 4.0
	30"/60"	5		4-5: SILTY CLAY: Black (5Y2.5/1); trace micaceous silt; trace fine to medium, subrounded sand; medium plasticity; soft clay; moist.	
2.1/0.2				5-10: Similar to above with color change to dark olive-gray (5Y3/2).	
2.5/0.3			CL		
	60"/60"	10		10-14.5: Silimar to above.	
0.8/0.2					
0.7/0.2					
					14.5
0.9/0.2	45"/60"	15		14.5-20: SANDY CLAY: Dark yellowish brown (10YR4/4); fine, subrounded, well graded sand; trace silt; medium plasticity, moderately stiff clay; moist.	
0.3/0.2			SC	17.5-20: Iron oxide staining throughout.	
1.2/0.2	48"/60"	20		20-21: Similar to above with decreasing clay; wet.	
					21.0
7.0/0.2			SP SC	21-24: SLIGHTLY SANDY CLAY; Dark yellowish brown (10YR4/4); fine to medium, subrounded, well graded sand; minor micaceous silt; plastic, soft clay; wet.	
15.3/0.2					24.0
			SC	24-25: SANDY CLAY: Light olive gray (5Y6/2); fine to coarse, subangular to subrounded, poorly graded sand; minor micaceous silt; stiff, low plasticity clay; moist.	25.0
6.0/0.2	10"/60"	25		25-30: SAND with SILT: Dark grayish brown (2.5Y4/2); fine to medium, subrounded, well graded sand; micaceous silt; wet.	
3.6/0.2			SP SM		
		30			

Continued Next Page

WELL DIAGRAM:
- Lockable Well Cap
- Concrete Annular Seal
- Neat Cement Grout
- 15 feet of 4" Sch 40 PVC Blank Riser
- Borehole Diameter = 12"
- Hydrated PureGold Medium Bentonite Chips
- #2/16 Monterey Sand Filter Pack
- 20 feet of 4" SCH 40 PVC 0.010-slot Slotted Screen with Threaded Couplings
- #2/16 Monterey Sand Filter Pack

SEALBEACH SEALBEACH.GPJ NEWGINT.GDT 4/28/08

CDM
111 Academy, Suite 150
Irvine, CA 92617
Phone: (949) 752-5452
Fax: (949) 725-3907

BORING/WELL CONSTRUCTION LOG

PROJECT NUMBER 50999-56254-6225.001.TK4.EQUIP **BORING/WELL NUMBER** PIW1

PROJECT NAME Naval Weapons Station-Seal Beach, Site 70 **DATE DRILLED** 3/26/08

Continued from Previous Page

PID (ppm)	RECOVERY (inches)	DEPTH (feet bgs)	U.S.C.S.	GRAPHIC LOG	LITHOLOGIC DESCRIPTION	CONTACT DEPTH	WELL DIAGRAM
8.3/2.0	34"/60"				30-32: Similar to above with very dark gray clay "balls;" wet.		#2/16 Monterey Sand Filter Pack
						32.0	
5.2/0.2			ML		32-35: SLIGHTLY SANDY SILT: Dark grayish brown (2.5Y2/4); fine to medium, subrounded, poorly graded sand; micaceous silt; moderately stiff, low plasticity clay; moist.		
						35.0	
32.0/2.0		35					Threaded SCH 40 PVC Bottom Cap
					Total Depth of Borehole = 35.5 feet bgs		
		40					
		45					
		50					
		55					
		60					

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CDM
111 Academy, Suite 150
Irvine, CA 92617
Phone: (949) 752-5452
Fax: (949) 725-3907

BORING/WELL CONSTRUCTION LOG

PROJECT NUMBER 50999-56254-6225.001.TK4.EQUIP
PROJECT NAME Naval Weapons Station-Seal Beach, Site 70
LOCATION Naval Weapons Station-Seal Beach
DRILLING METHOD CME 75 Hollow Stem Auger
SAMPLING METHOD 5' CA-Modified Split Spoon
GROUND SURFACE ELEVATION (FT MSL)
TOP OF CASING ELEVATION (FT MSL)
LOGGED BY Kristeen Bennett
REMARKS

BORING/WELL NUMBER PIW2
DATE DRILLED 3/27/08
CASING TYPE/DIAMETER 4" Schedule 40 PVC
SCREEN TYPE/SLOT 4" PVC 0.010 Slot
GRAVEL PACK TYPE #2/16 Lapis Lustre Sand
GROUT TYPE/QUANTITY Neat Cement Grout / Medium Bentonite Chips
STATIC WATER LEVEL (FT BELOW TOC)
GROUND WATER ELEVATION (FT MSL)

PID (ppm)	RECOVERY (inches)	DEPTH (feet bgs)	U.S.C.S.	LITHOLOGIC DESCRIPTION	CONTACT DEPTH
				4" Cored asphalt (diameter 18")	
			SM	0.3-0.8: GRAVELLY SILTY SAND: Dark grayish brown (2.5Y4/2); fine to coarse, subangular to subrounded, poorly graded sand; fine to medium, subangular, well graded gravel; micaceous silt; moist.	
				0.8-4: Similar to above with change in color to Olive gray (5Y4/2)	4.0
	30"/60"	5		4-5: SILTY CLAY: Black (2.5Y2.5/1); micaceous silt; moderately stiff, high plasticity clay; moist.	
				5-10: Similar to above with color change to dark olive gray (5Y3/2) with increasing depth.	
2.3/0.3					
2.0/0.3	40"/60"	10	CL ML	10-14: Similar to above with color change to olive gray (5Y4.5/2) with increasing depth.	
0.5/0.0					
1.1/0.2					
2.0/0.3	48"/60"	15		14-15: Similar to above with trace fine to medium, subangular, poorly graded gravel; organic material "balls" and iron oxide staining throughout.	15.0
				15-20: SILTY SANDY CLAY: Dark olive gray (5Y3/2); fine, subrounded well graded sand; micaceous silt; moderately stiff, medium plasticity clay; moist.	
				Iron oxide mottling from 15-19.	
3.2/0.4			CL ML		
4.3/0.4	28"/60"	20		20-22: Similar to above.	
					22.0
28.5/0.5				22-25: CLAYEY SILTY SAND: Olive gray (5Y4/2); fine to medium, subrounded, poorly graded sand; micaceous silt; soft, low plasticity clay; wet.	
197/0.8	38"/60"	25	SM	25-28: Similar to above with decreasing sand content; wet.	
42.7/0.3					
					28.0
			ML	28-28.5: SANDY SILT: Olive (5Y5/3); fine, subrounded,	28.5
			SM	well graded sand; laminated micaceous silt; moist.	29.0
49.8/0.4			ML	28.5-29: Similar to 25-28.	29.5
		30		*Continued Next Page*	

WELL DIAGRAM:
- Lockable Well Cap
- Concrete Annular Seal
- Neat Cement Grout
- 15 feet of 4" Sch 40 PVC Blank Riser
- Borehole Diameter = 12"
- Hydrated PureGold Medium Bentonite Chips
- #2/16 Monterey Sand Filter Pack
- 20 feet of 4" SCH 40 PVC 0.010-slot Slotted Screen with Threaded Couplings
- #2/16 Monterey Sand Filter Pack

SEALBEACH SEALBEACH.GPJ NEWGINT.GDT 4/28/08

CDM
111 Academy, Suite 150
Irvine, CA 92617
Phone: (949) 752-5452
Fax: (949) 725-3907

BORING/WELL CONSTRUCTION LOG

PROJECT NUMBER 50999-56254-6225.001.TK4.EQUIP **BORING/WELL NUMBER** PIW2

PROJECT NAME Naval Weapons Station-Seal Beach, Site 70 **DATE DRILLED** 3/27/08

Continued from Previous Page

PID (ppm)	RECOVERY (inches)	DEPTH (feet bgs)	U.S.C.S.	GRAPHIC LOG	LITHOLOGIC DESCRIPTION	CONTACT DEPTH	WELL DIAGRAM
135/0.3 25.7/0.2	48"/60"		SM		29-29.5: Similar to 28-28.5. 29.5-30: Similar to 28.5-29. 30-33: Similar to above.	33.0	#2/16 Monterey Sand Filter Pack
			CL ML		33-34.5: SILTY CLAY: Olive (5Y4/3); micaceous, laminated silt; stiff, high plasticity clay; moist.	34.5	
		35	ML		34.5-35: SANDY SILT: Olive (5Y5/3); fine, subrounded, well graded sand; micaceous, laminated silt; moist.	35.0	Threaded SCH 40 PVC Bottom Cap
					Total Depth of Borehole = 35.5 feet bgs		
		40					
		45					
		50					
		55					
		60					

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CDM
111 Academy, Suite 150
Irvine, CA 92617
Phone: (949) 752-5452
Fax: (949) 725-3907

BORING/WELL CONSTRUCTION LOG

PROJECT NUMBER 50999-56254-6225.001.TK4.EQUIP
PROJECT NAME Naval Weapons Station-Seal Beach, Site 70
LOCATION Naval Weapons Station-Seal Beach
DRILLING METHOD CME 75 Hollow Stem Auger
SAMPLING METHOD 5' CA-Modified Split Spoon
GROUND SURFACE ELEVATION (FT MSL)
TOP OF CASING ELEVATION (FT MSL)
LOGGED BY Kristeen Bennett
REMARKS

BORING/WELL NUMBER PIW3
DATE DRILLED 3/25/08
CASING TYPE/DIAMETER 4" Schedule 40 PVC
SCREEN TYPE/SLOT 4" PVC 0.010 Slot
GRAVEL PACK TYPE #2/16 Lapis Lustre Sand
GROUT TYPE/QUANTITY Neat Cement Grout / Medium Bentonite Chips
STATIC WATER LEVEL (FT BELOW TOC)
GROUND WATER ELEVATION (FT MSL)

PID (ppm)	RECOVERY (inches)	DEPTH (feet bgs)	U.S.C.S.	LITHOLOGIC DESCRIPTION	CONTACT DEPTH
				(4") Cored asphalt (18" diam.)	0.4
			CL ML	0-4: GRAVELLY SILTY SAND: Olive Brown (2.5Y4/3); fine to coarse, subangular to subrounded, poorly graded sand; subangular medium to coarse, poorly graded gravel; micaceous silt; moist.	
					4.0
			CL	4-5: SLIGHTLY SILTY CLAY: Black (2.5Y2.5/1); micaceous silt; moderately stiff; medium plasticity clay; moist.	5.0
	60"/60"	5			
1.0/0.0			CL	5-10: Lithology similar to above with color change from very dark gray (2.5Y3/1) to dark grayish brown (2.5Y4/2).	
0.5/0.0					
					10.0
0.0/0.0	35"/60"	10	CL	10-11: Similar to above	11.0
0.7/0.0			CL	11-13: Similar to above with "spongy" texture	
					13.0
4.9/0.0			CL	13-13.5: Similar to 5-10 ft with light gray clay seams.	13.5
			CL	13.5-15: SLIGHTLY SANDY CLAY: Very dark grayish brown (10YR3/2); fine, well-graded, subrounded sand; trace micaceous silt; stiff; medium plasticity clay; moist; iron oxide staining throughout.	15.0
1.8/0.0	50"/60"	15			
1.8/0.0			ML	15-17.5: Similar to above with increasing sand content	
					17.5
0.0/0.0			SC	17.5-20: SANDY CLAY: Very dark grayish brown (2.5Y3/2); fine to medium subrounded, poorly graded sand; trace micaceous silt; stiff; medium plasticity clay; moist; iron oxide staining throughout.	20.0
2.3/0.0	28"/60"	20		20-24: SLIGHTLY CLAYEY SILTY SAND: Dark grayish brown (2.5Y4/2); fine to medium subrounded, poorly graded sand; micaceous silt; trace, soft, high plasticity clay; wet.	
9.3/0.0					
58.1/0.0			SM		
					24.0
			ML	24-25: SLIGHTLY SANDY CLAYEY SILT: Grayish brown (2.5Y5/2); fine to coarse, subangular to subrounded, poorly graded sand; moderately stiff, medium plasticity clay; micaceous silt; moist.	25.0
18.6/0.0	30"/60"	25			
51.3/0.0			SM	25-30: SILTY SAND: Olive brown (2.5Y4/33); fine to medium subrounded, sand; micaceous silt; wet.	
75.7/0.0					
		30			30.0

Continued Next Page

WELL DIAGRAM:
- Lockable Well Cap
- Concrete Annular Seal
- Neat Cement Grout
- 15 feet of 4" Sch 40 PVC Blank Riser
- Borehole Diameter = 12"
- Hydrated PureGold Medium Bentonite Chips
- #2/16 Monterey Sand Filter Pack
- 20 feet of 4" SCH 40 PVC 0.010-slot Slotted Screen with Threaded Couplings
- #2/16 Monterey Sand Filter Pack

SEALBEACH SEALBEACH.GPJ NEWGINT.GDT 4/28/08

CDM
111 Academy, Suite 150
Irvine, CA 92617
Phone: (949) 752-5452
Fax: (949) 725-3907

BORING/WELL CONSTRUCTION LOG

PROJECT NUMBER 50999-56254-6225.001.TK4.EQUIP **BORING/WELL NUMBER** PIW3

PROJECT NAME Naval Weapons Station-Seal Beach, Site 70 **DATE DRILLED** 3/25/08

Continued from Previous Page

PID (ppm)	RECOVERY (inches)	DEPTH (feet bgs)	U.S.C.S.	GRAPHIC LOG	LITHOLOGIC DESCRIPTION	CONTACT DEPTH	WELL DIAGRAM
	50"/60"		SM		30-31: Similar to above; wet.	31.0	
16.5/0.0			ML		31-32: CLAYEY SILT; Olive gray (5Y5/2); micaceous silt; stiff; medium plasticity clay; moist.	32.0	#2/16 Monterey Sand Filter Pack
			SM		32-33: Similar to 30-31 ft.	33.0	
7.8/0.0			ML		33-34: Similar to 31-32 ft.	34.0	
			SM		34-35: Similar to 32-33 ft.	35.0	
273/0.0		35			Total Depth of Boring = 35.5 ft bgs Added 5 gallons of water for heaving sands.		Threaded SCH 40 PVC Bottom Cap
		40					
		45					
		50					
		55					
		60					

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CDM
111 Academy, Suite 150
Irvine, CA 92617
Phone: (949) 752-5452
Fax: (949) 725-3907

BORING/WELL CONSTRUCTION LOG

PROJECT NUMBER 50999-56254-6225.001.TK4.EQUIP
PROJECT NAME Naval Weapons Station-Seal Beach, Site 70
LOCATION Naval Weapons Station-Seal Beach
DRILLING METHOD CME 75 Hollow Stem Auger
SAMPLING METHOD 5' CA-Modified Split Spoon
GROUND SURFACE ELEVATION (FT MSL)
TOP OF CASING ELEVATION (FT MSL)
LOGGED BY Kristeen Bennett
REMARKS

BORING/WELL NUMBER PMW2
DATE DRILLED 3/26/08
CASING TYPE/DIAMETER 4" Schedule 40 PVC
SCREEN TYPE/SLOT 4" PVC 0.010 Slot
GRAVEL PACK TYPE #2/16 Lapis Lustre Sand
GROUT TYPE/QUANTITY Neat Cement Grout / Medium Bentonite Chips
STATIC WATER LEVEL (FT BELOW TOC)
GROUND WATER ELEVATION (FT MSL)

PID (ppm)	RECOVERY (inches)	DEPTH (feet bgs)	U.S.C.S.	GRAPHIC LOG	LITHOLOGIC DESCRIPTION	CONTACT DEPTH
					4" Cored Asphalt(diameter 18")	0.3
			SM		0.25-4: GRAVELLY SILTY SAND: Yellowish brown (10YR5/4); fine to coarse subangular to subrounded, poorly graded sand; micaceous silt; fine to coarse, subangular, poorly graded gravel; moist; some iron oxide staining.	4.0
	26"/60"	5			4-10: SILTY CLAY: Dark olive gray (5Y3/2) to Olive gray (5Y4/2); micaceous silt; moderately stiff, medium plasticity clay; moist.	
1.7/0.2			CL			
1.8/0.5	40"/60"	10				10.0
1.2/0.2					10-15: Similar to above with color change at 14.5 to brown (10YR4/3)	
1.6/0.2			CL			
2.3/0.4	40"/60"	15				15.0
1.9/0.2					15-20: SLIGHTLY SILTY SANDY CLAY: Dark yellowish brown (10YR3/4) fine to medium, subrounded, poorly graded sand; minor micaceous silt; moderately stiff, medium plasticity clay; moist.	
			CL			
3.0/0.6						
2.1/0.6	48"/60"	20	CL		20-21.5: Similar to above with decreasing clay and increasing sand contents.	20.0
4.3/0.9						21.5
4.2/0.7					21.5-24.5: SILTY CLAYEY SAND: Olive brown (2.5Y4/3); fine to medium subrounded, poorly graded sand; micaceous silt; medium plasticity; soft; clay; wet.	24.5
9.1/0.0	30"/60"	25			24.5-25: SLIGHTLY SANDY CLAYEY SILT: Dark grayish brown (2.5Y4/2); trace, fine to medium, subrounded, poorly graded sand; laminated micaceous silt; low plasticity, soft clay; moist; heavily bioturbated.	25.0
					25-26: SLIGHTLY SANDY CLAY: Dark grayish brown (10YR4/2); trace, fine to coarse, subangular, soft; low plasticity clay; wet; heavily bioturbated.	26.0
6.1/0.8					26-26.5: SILTY CLAY: Olive gray (5Y5/2); micaceous silt; soft; low plasticity clay;wet; heavily bioturbated.	26.5
16.4/0.7					25-26: SILTY CLAY; Olive gray (5Y4/2); micaceous silt;	
		30				30.0

Continued Next Page

WELL DIAGRAM:
- Lockable Well Cap
- Concrete Annular Seal Borehole Diameter = 12"
- Neat Cement Grout
- 15 feet of 4" Sch 40 PVC Blank Riser
- Hydrated PureGold Medium Bentonite Chips
- #2/16 Monterey Sand Filter Pack
- 20 feet of 4" SCH 40 PVC 0.010-slot Slotted Screen with Threaded Couplings
- #2/16 Monterey Sand Filter Pack

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CDM
111 Academy, Suite 150
Irvine, CA 92617
Phone: (949) 752-5452
Fax: (949) 725-3907

BORING/WELL CONSTRUCTION LOG

PROJECT NUMBER 50999-56254-6225.001.TK4.EQUIP **BORING/WELL NUMBER** PMW2

PROJECT NAME Naval Weapons Station-Seal Beach, Site 70 **DATE DRILLED** 3/26/08

Continued from Previous Page

PID (ppm)	RECOVERY (inches)	DEPTH (feet bgs)	U.S.C.S.	GRAPHIC LOG	LITHOLOGIC DESCRIPTION	CONTACT DEPTH	WELL DIAGRAM
	52"/60"				fine to medium subrounded, poorly graded sand; wet.		
33.1/0.6					30-31: CLAYEY SILT: Light olive brown (2.5 Y5/3); alternating laminations of clay and silt; micaceous silt; soft; high plasticity clay moist	31.0	
					31-32.5: SILTY CLAY: Olive (5Y5/3); micaceous silt; moderately stiff, medium plasticity clay; moist some iron-oxide staining	32.5	#2/16 Monterey Sand Filter Pack
27.0/0.8					32.5-34: Similar to 30-31 with trace subangular to subrounded, poorly graded, fine to medium gravel.	34.0	
29.7/0.9		35			34-35: CLAYEY SANDY SILT: Olive gray (5Y4/2); fine, subrounded sand; soft, high plasticity clay; micaceous silt; moist.	35.0	Threaded SCH 40 PVC Bottom Cap
					Total depth of bore hole is 35.5 ft bgs		
		40					
		45					
		50					
		55					
		60					

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CDM
111 Academy, Suite 150
Irvine, CA 92617
Phone: (949) 752-5452
Fax: (949) 725-3907

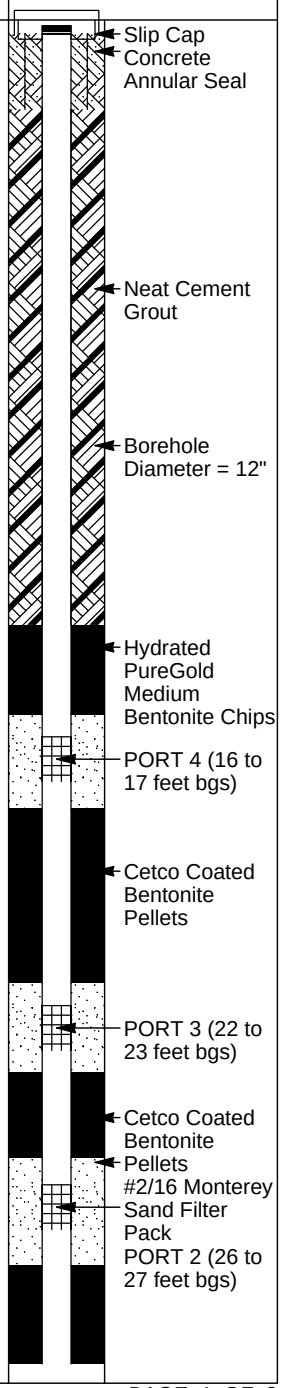
BORING/WELL CONSTRUCTION LOG

PROJECT NUMBER 50999-56254-6225.001.TK4.EQUIP
PROJECT NAME Naval Weapons Station-Seal Beach, Site 70
LOCATION Naval Weapons Station-Seal Beach
DRILLING METHOD CME 75 Hollow Stem Auger
SAMPLING METHOD 5' CA-Modified Split Spoon
GROUND SURFACE ELEVATION (FT MSL)
TOP OF CASING ELEVATION (FT MSL)
LOGGED BY Kristeen Bennett
REMARKS Port designation are labeled correctly

BORING/WELL NUMBER PMW3
DATE DRILLED 3/31/08
CASING TYPE/DIAMETER 4" Schedule 40 PVC
SCREEN TYPE/SLOT 4" PVC 0.010 Slot
GRAVEL PACK TYPE #2/16 Lapis Lustre Sand
GROUT TYPE/QUANTITY Neat Cement Grout / Medium Bentonite Chips
STATIC WATER LEVEL (FT BELOW TOC)
GROUND WATER ELEVATION (FT MSL)

PID (ppm)	RECOVERY (inches)	DEPTH (feet bgs)	U.S.C.S.	LITHOLOGIC DESCRIPTION	CONTACT DEPTH
				2" asphalt.	0.2
				Upper 5 ft lithology same as other borings.	
0.0/0.0	40"/60"	5	SM	5-6: GRAVELLY SILTY SAND: Yellowish brown (10YR5/6); fine to coarse subangular to subrounded, poorly graded sand; fine to coarse, subangular, poorly graded gravel; micaceous silt; moist.	5.0 6.0
			CL ML	6-10: SILTY CLAY: Very dark grayish brown (2.5Y3/2); micaceous silt; soft, high plasticity clay; moist.	
	40"/60"	10		10-14.5: Similar to above with color change to olive gray (5Y4/2).	10.0
0.0/0.0			CL ML		
1.9/0.2					14.5
	42"/60"	15	CL ML CL	14.5-15: SLIGHTLY SANDY SILTY CLAY: Dark grayish brown (10YR4/2); fine to coarse subangular to subrounded, poorly graded sand; micaceous silt; soft; highly plasticity clay; moist.	15.0
				15-18: GRAVELLY SANDY CLAY: Brown (10YR4/3); fine to coarse, subangular to subrounded; poorly graded sand; soft, medium plasticity clay; wet.	18.0
1.6/0.2			SC	18-20: CLAYEY SAND: Dark yellowish brown (10YR4/4); fine to medium, subangular, well graded sand; trace micaceous silt; moderately stiff, medium plasticity clay; moist.	
	8"/60"	20		20-25: CLAYEY SAND: Dark yellowish brown (10YR4/4); fine to medium, subangular, well graded ; trace micaceous silt; soft; medium plasticity clay; wet.	20.0
			SM		
	30"/60"	25	SM	25-27: SLIGHTLY CLAYEY SILTY SAND: Olive brown (2.5Y4/4); fine to medium subangular, well graded sand; micaceous silt; trace clay; wet.	25.0 27.0
			SC	27-28: SLIGHTLY GRAVELLY CLAYEY SAND: Light olive brown (2.5Y5/3) fine to medium, subangular well graded sand; fine to meidum subangular, poorly graded gravel; soft, high plasticity clay; wet.	28.0
			SM	28-30: SLIGHTLY CLAYEY SILTY SAND: Olive (5Y4/4);	30.0
		30		*Continued Next Page*	

WELL DIAGRAM



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CDM
111 Academy, Suite 150
Irvine, CA 92617
Phone: (949) 752-5452
Fax: (949) 725-3907

BORING/WELL CONSTRUCTION LOG

PROJECT NUMBER 50999-56254-6225.001.TK4.EQUIP **BORING/WELL NUMBER** PMW3

PROJECT NAME Naval Weapons Station-Seal Beach, Site 70 **DATE DRILLED** 3/31/08

Continued from Previous Page

PID (ppm)	RECOVERY (inches)	DEPTH (feet bgs)	U.S.C.S.	GRAPHIC LOG	LITHOLOGIC DESCRIPTION	CONTACT DEPTH	WELL DIAGRAM
	58"/60"		SC		fine to medium subangular, well graded sand; micaceous silt; trace clay; wet.	31.0	Cetco Coated Bentonite Pellets
			CL ML		30-31: Similar to 27-28'. 31-33: SILTY CLAY: Olive (5Y4/3); micaceous silt; moderately stiff, high plasticity clay; moist.	33.0	
			ML		33-33.5: SILT: Olive (5Y5/4); laminated micaceous silt; moist.	33.5	
			CL			34.0	
			ML ML		33.5-34: Similar to 31-33'; dry to moist. 34-35: SLIGHTLY SANDY SILT: Olive (5Y4/4); fine, well graded, subangular sand; laminated micaceous silt; moist.	35.0	PORT 1 (34 to 35 feet bgs) #2/16 Monterey Sand Filter Pack
		35			Total Depth of Boring = 36 ft bgs.		
		40					
		45					
		50					
		55					
		60					

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CDM
111 Academy, Suite 150
Irvine, CA 92617
Phone: (949) 752-5452
Fax: (949) 725-3907

BORING/WELL CONSTRUCTION LOG

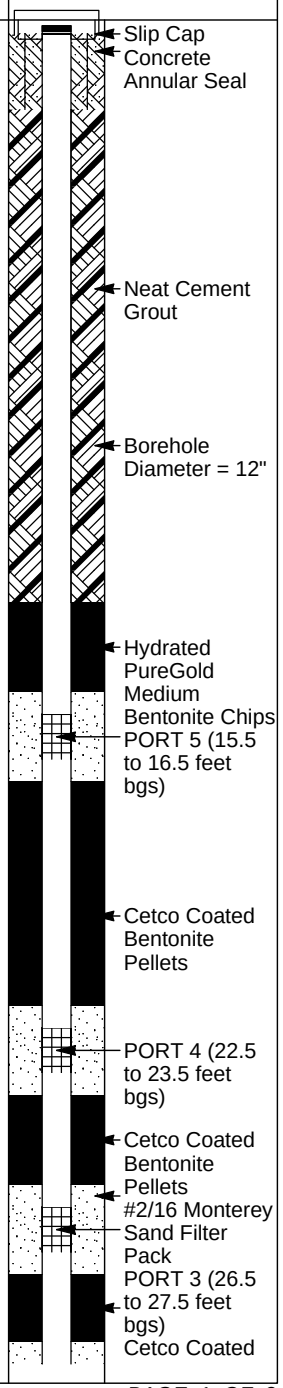
PROJECT NUMBER 50999-56254-6225.001.TK4.EQUIP
PROJECT NAME Naval Weapons Station-Seal Beach, Site 70
LOCATION Naval Weapons Station-Seal Beach
DRILLING METHOD CME 75 Hollow Stem Auger
SAMPLING METHOD 5' CA-Modified Split Spoon
GROUND SURFACE ELEVATION (FT MSL)
TOP OF CASING ELEVATION (FT MSL)
LOGGED BY Kristeen Bennett
REMARKS Port designation are labeled correctly

BORING/WELL NUMBER PMW4
DATE DRILLED 4/1/08
CASING TYPE/DIAMETER 4" Schedule 40 PVC
SCREEN TYPE/SLOT 4" PVC 0.010 Slot
GRAVEL PACK TYPE #2/16 Lapis Lustre Sand
GROUT TYPE/QUANTITY Neat Cement Grout / Medium Bentonite Chips
STATIC WATER LEVEL (FT BELOW TOC)
GROUND WATER ELEVATION (FT MSL)

PID (ppm)	RECOVERY (inches)	DEPTH (feet bgs)	U.S.C.S.	GRAPHIC LOG	LITHOLOGIC DESCRIPTION	CONTACT DEPTH
					2" thick asphalt cone (18"diamter) . See other logs for lithology; it does not vary between holes.	
	26"/60"	5				5.0
0.0/0.0			CL ML		5-10: SILTY CLAY: Black (2.5Y2.5/1) to olivy brown (2.5Y4/3); micaceous silt; high plasticity; soft clay; moist.	
0.0/0.0						
0.0/0.0	60"/60"	10				10.0
0.0/0.0			CL ML		10-14: Similar to above with color change to olive gray (5Y4/2) to grayish brown (2.5Y5/1).	
0.0/0.0						14.0
0.0/0.0			CL ML		14-15: SLIGHTLY SANDY SILTY CLAY: Dark yellowish brown (10YR4/4); fine to coarse, subangular to subrounded; poorly graded sand; micaceous silt; moderatly stiff, medium plastic clay, moist.	15.0
	28"/60"	15	CL ML		15-16: Similar to above; water visible.	16.0
0.2/0.1					16-20: SANDY CLAY: Dark yellowish brown (10R4/4) to dark grayish brown (2.5Y4/2); fine to medium, subrounded, well graded sand; stiff, low plasticity clay; moist.	
0.4/0.2			CL ML			
1.0/0.0	32"/60"	20				20.0
6.8/0.1			CL		20-22: Similar to above	
14.8/0.2						22.0
			SM		* subangular to subrounded, medium gravel in upper part of core barrel from 20-25, slough?	
29.1/0.2					22-25: SLIGHTLY CLAYEY SILTY SAND: Olive brown 2.5Y4/3); fine to medium subrounded well graded micaceous silt; trace, soft, high plasticity clay; wet.	
	18"/60"	25				25.0
0.3/0.2					25-29.5: Similar to above with more medium grained sand.	
0.4/0.2			SM			
0.9/0.2						29.5
		30	SM		29.5-30: GRAVELLY SILTY SAND: Olive (2.5Y4/3); fine to	30.0

Continued Next Page

WELL DIAGRAM



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CDM
111 Academy, Suite 150
Irvine, CA 92617
Phone: (949) 752-5452
Fax: (949) 725-3907

BORING/WELL CONSTRUCTION LOG

PROJECT NUMBER 50999-56254-6225.001.TK4.EQUIP **BORING/WELL NUMBER** PMW4

PROJECT NAME Naval Weapons Station-Seal Beach, Site 70 **DATE DRILLED** 4/1/08

Continued from Previous Page

PID (ppm)	RECOVERY (inches)	DEPTH (feet bgs)	U.S.C.S.	GRAPHIC LOG	LITHOLOGIC DESCRIPTION	CONTACT DEPTH	WELL DIAGRAM
	60"/60		SM		coarse, subrounded, poorly graded sand; fine to medium, subangular, poorly graded gravel; micaceous silt; wet.	30.5	Bentonite Pellets
			ML		30-30.5: Similar to above.	31.5	PORT 2 (30 to 31 feet bgs)
			CL ML		30.5-31.5: SLIGHTLY SANDY SILT: Light olive gray (5Y6/2); fine, subrounded well graded sand; laminated micaceous silt; moist.	33.0	
			ML		31.5-33: SILTY CLAY: Light gray (2.5Y7/2); micaceous silt; moderately stiff, medium plasticity clay; moist.		PORT 1 (33.5 to 34.5 feet bgs)
			CL ML		33-34.5: SANDY SILT: Olive 2/5Y4/3); fine, subrounded well graded sand; laminated micaceous silt; moist.	34.5 35.0	#2/16 Monterey Sand Filter Pack
		35			34.5-35: Similar to 31.5-33'. Total Depth of Boring = 36 ft bgs.		
		40					
		45					
		50					
		55					
		60					

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CDM
111 Academy, Suite 150
Irvine, CA 92617
Phone: (949) 752-5452
Fax: (949) 725-3907

BORING/WELL CONSTRUCTION LOG

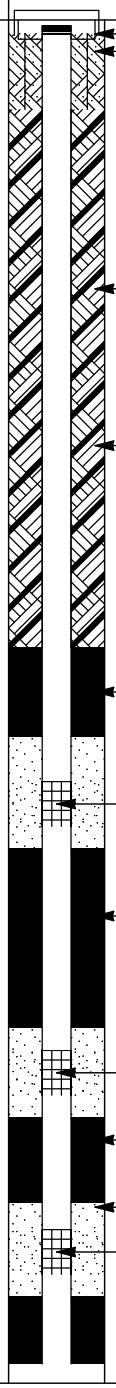
PROJECT NUMBER 50999-56254-6225.001.TK4.EQUIP
PROJECT NAME Naval Weapons Station-Seal Beach, Site 70
LOCATION Naval Weapons Station-Seal Beach
DRILLING METHOD CME 75 Hollow Stem Auger
SAMPLING METHOD 5' CA-Modified Split Spoon
GROUND SURFACE ELEVATION (FT MSL)
TOP OF CASING ELEVATION (FT MSL)
LOGGED BY Kristeen Bennett
REMARKS Port designation are labeled correctly

BORING/WELL NUMBER PMW5
DATE DRILLED 4/1/08
CASING TYPE/DIAMETER 4" Schedule 40 PVC
SCREEN TYPE/SLOT 4" PVC 0.010 Slot
GRAVEL PACK TYPE #2/16 Lapis Lustre Sand
GROUT TYPE/QUANTITY Neat Cement Grout / Medium Bentonite Chips
STATIC WATER LEVEL (FT BELOW TOC)
GROUND WATER ELEVATION (FT MSL)

PID (ppm)	RECOVERY (inches)	DEPTH (feet bgs)	U.S.C.S.	GRAPHIC LOG	LITHOLOGIC DESCRIPTION	CONTACT DEPTH
			SM		2" Cored asphalt (18"diameter) See other logs for lithology; it does not vary between holes.	0.2
	22"/60"	5	CL ML		5-6: GRAVELLY SILTY SAND: Yellowish brown (10YR 5/6); fine to coarse, subangular to subrounded, poorly graded sand; micaceous silt; fine to medium, subangular, poorly graded gravel; moist.	5.0 6.0
0.0/0.0			CL ML		6-10: SILTY CLAY: Black (2.5Y2.5/1) to dark olive; micaceous silt; moderately stiff, high plasticity clay; moist.	
0.0/0.0						
0.0/0.0	60"/60"	10			10-13.5: Similar to above with color change to olive gray (5Y4/2).	10.0
			CL ML			
0.0/0.0						13.5
			CL ML		13.5-15: SLIGHTLY GRAVELLY SILTY CLAY: Dark yellowish brown (10YR4/4); micaceous silt, fine to medium, subangular to subrounded, poorly graded gravel, moderatly stiff, high plasticity clay; moist; "balls" of black organic clay.	15.0
	46"/60"	15	CL ML		15-16: Similar to above	16.0
1.9/0.0			CL ML		16-19: SANDY SILTY CLAY: Brown (10YR5.3) to yellowish brown (10YR5/4); fine, subrounded, well graded sand; micaceous silt; stiff, medium plasticity clay; moist; iron-oxide mottling throughout.	19.0
1.0/0.0			CL ML		19-20: Similar to above with color change to olive gray (5Y4/2).	20.0
	34"/60"	20			20-22: Similar to above; moist to wet.	
14.3/0.0			CL ML			
9.3/0.0						22.0
			SM		22-24.5: SLIGHTLY CLAYEY SILTY SAND: Olive gray (5Y4/2) to oive brown (2.5Y4/3); fine to medium subrounded poorly graded sand; micaceous silt; trace clay; wet.	
15.9/0.0						24.5
			CL ML		Organic layers at 23.5' and 24'.	25.0
	26"/60"	25			24.5-25: SILTY CLAY: Light gray (2.5Y7/2); micaceous silt; soft low plasticity clay; moist.	
0.0/0.0					25-29.5: Similar to 22-24.5'; wet.	
0.9/0.0			SM			
0.4/0.0						29.5
		30	ML		29.5-30: SLIGHTLY SANDY SILT: Light olive gray	30.0

Continued Next Page

WELL DIAGRAM



SEALBEACH SEALBEACH.GPJ NEWGINT.GDT 4/28/08

CDM
111 Academy, Suite 150
Irvine, CA 92617
Phone: (949) 752-5452
Fax: (949) 725-3907

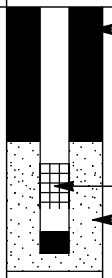
BORING/WELL CONSTRUCTION LOG

PROJECT NUMBER 50999-56254-6225.001.TK4.EQUIP **BORING/WELL NUMBER** PMW5

PROJECT NAME Naval Weapons Station-Seal Beach, Site 70 **DATE DRILLED** 4/1/08

Continued from Previous Page

PID (ppm)	RECOVERY (inches)	DEPTH (feet bgs)	U.S.C.S.	GRAPHIC LOG	LITHOLOGIC DESCRIPTION	CONTACT DEPTH	WELL DIAGRAM
	54"/60"		SM		(5Y6/2); fine, subrounded well graded sand; micaceous	30.5	
			ML		silt; moist.	31.0	
19.7/0.0			CL		30-30.5: Similar to 25-29.5'; wet.		
			ML		30.5-31: Similar to 29.5-30'.		
					31-32.5: Similar to 24.5'- 25'.	32.5	
			ML		32.5-33.5: SLIGHTLY SANDY SILT: Olive gray (5Y5/2);		
87.4/0.0					laminated micaceous silt; trace; fine, well graded,	33.5	
14.5/0.0			ML		subrounded sand; moist.		
					33.5-34.5: SANDY SILT: Olive (2.5)Y4/3); fine, well	34.5	
			CL		graded, subrounded sand; laminated micaceous silt;	35.0	
		35	ML		moist.		
					34.5-35: Similar to 31'-32.5'.		
					Total Depth of Boring = 35.9 ft bgs		
					Heaving Sands from 28-35 ft bgs		
					Added 5 gallons of water to borehole when heaving sands encountered.		
		40					
		45					
		50					
		55					
		60					



Cetco Coated Bentonite Pellets

PORT 1 (33.5 to 34.5 feet bgs)

#2/16 Monterey Sand Filter Pack

SEALBEACH SEALBEACH.GPJ NEWGINT.GDT 4/28/08

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111 Academy, Suite 150
Irvine, CA 92617
Phone: (949) 752-5452
Fax: (949) 725-3907

BORING/WELL CONSTRUCTION LOG

PROJECT NUMBER 50999-56254-6225.001.TK4.EQUIP
PROJECT NAME Naval Weapons Station-Seal Beach, Site 70
LOCATION Naval Weapons Station-Seal Beach
DRILLING METHOD CME 75 Hollow Stem Auger
SAMPLING METHOD 5' CA-Modified Split Spoon
GROUND SURFACE ELEVATION (FT MSL)
TOP OF CASING ELEVATION (FT MSL)
LOGGED BY Kristeen Bennett
REMARKS

BORING/WELL NUMBER PMW6
DATE DRILLED 3/27/08
CASING TYPE/DIAMETER 4" Schedule 40 PVC
SCREEN TYPE/SLOT 4" PVC 0.010 Slot
GRAVEL PACK TYPE #2/16 Lapis Lustre Sand
GROUT TYPE/QUANTITY Neat Cement Grout / Medium Bentonite Chips
STATIC WATER LEVEL (FT BELOW TOC)
GROUND WATER ELEVATION (FT MSL)

PID (ppm)	RECOVERY (inches)	DEPTH (feet bgs)	U.S.C.S.	GRAPHIC LOG	LITHOLOGIC DESCRIPTION	CONTACT DEPTH
			SM		4" Cored asphalt (18" diam.).	0.2
			SM		0.3-0.8: GRAVELLY SILTY SAND: Brown (10YR4/3); fine to coarse, subangular to subrounded, poorly graded sand; fine to medium subangular gravel; micaceous silt; moist.	0.8
			CL ML		0.8-4: SLIGHTLY CLAYEY SILTY SAND: Olive gray (5Y5/2); fine to coarse, subangular to subrounded, poorly graded sand; micaceous silt; soft, medium plasticity clay; moist.	4.0
			CL ML		4-5: SILTY CLAY: Black (2.5Y2.5/1); micaceous silt; soft, high plasticity clay; moist.	5.0
1.5/0.6	26"/60"	5			5-10: Similar to above with color change to very dark gray (5Y4/1) with depth.	
2.6/0.9			CL ML			
3.8/0.8	50"/60"	10			10-14: Similar to above with color change to dark gray (5Y4/1) with depth.	10.0
3.1/0.8			CL ML			
3.8/0.4	42"/60"	15	CL		14-15: SLIGHTLY SANDY CLAY: Brown (10YR4/3); fine, subrounded, well graded sand; trace micaceous silt; moderately stiff, high plasticity clay; moist; "balls" of organic rich clay.	14.0 15.0
3.3/0.3			CL		15-19: Similar to above with increasing sand with depth and color banding of brown and dark olive gray.	
5.4/0.5	20"/60"	20	SC		19-20: CLAYEY SAND: Dark olive gray (5Y3/2); fine, subrounded, well graded sand; trace micaceous silt; moderately stiff, medium plasticity clay; moist.	19.0 20.0
8.4/0.6			SM		20-22: SLIGHTLY CLAYEY SILTY SAND: Olive gray (5Y4/2); fine to medium, subrounded, well graded sand; micaceous silt; moderately stiff, medium plasticity clay; moist to wet.	22.0
36.4/0.0	30"/60"	25	SM		22-25: SILTY SAND: Olive gray (5Y4/2); fine to medium, subrounded, well graded sand; micaceous silt; wet. 25-30: Similar to above.	25.0
37.1/0.5			SM			
24.7/0.1		30				30.0

Continued Next Page

WELL DIAGRAM
- Lockable Well Cap
- Concrete Annular Seal
- Borehole Diameter = 12"
- Neat Cement Grout
- 15 feet of 4" Sch 40 PVC Blank Riser
- Hydrated PureGold Medium Bentonite Chips
- #2/16 Monterey Sand Filter Pack
- 20 feet of 4" SCH 40 PVC 0.010-slot Slotted Screen with Threaded Couplings
- #2/16 Monterey Sand Filter Pack

SEALBEACH SEALBEACH.GPJ NEWGINT.GDT 4/28/08

CDM
111 Academy, Suite 150
Irvine, CA 92617
Phone: (949) 752-5452
Fax: (949) 725-3907

BORING/WELL CONSTRUCTION LOG

PROJECT NUMBER 50999-56254-6225.001.TK4.EQUIP **BORING/WELL NUMBER** PMW6

PROJECT NAME Naval Weapons Station-Seal Beach, Site 70 **DATE DRILLED** 3/27/08

Continued from Previous Page

PID (ppm)	RECOVERY (inches)	DEPTH (feet bgs)	U.S.C.S.	GRAPHIC LOG	LITHOLOGIC DESCRIPTION	CONTACT DEPTH	WELL DIAGRAM
	48"/60"				30-32: Similar to above.		
15.5/0.2			SM			32.0	
			CL		32-32.5: SILTY CLAY: Olive (5Y5/3): micaceous silt; moderately stiff, high plasticity clay; moist.	32.5	#2/16 Monterey Sand Filter Pack
25.6/0.3			ML		32.5-34.5: SLIGHTLY SANDY SILT: Light olive brown (2.5Y5/3); fine, well graded, subrounded sand; laminated micaceous silt; trace high plasticity, soft clay; moist.	34.5	
			ML		34.5-35: SANDY SILT: Olive (5Y4/4); fine, well graded, subrounded sand; micaceous silt; moist.	35.0	
86.3/0.4		35			Total Depth of Boring = 35.5 ft bgs.		Threaded SCH 40 PVC Bottom Cap
		40					
		45					
		50					
		55					
		60					

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Fax: (949) 725-3907

BORING/WELL CONSTRUCTION LOG

PROJECT NUMBER 50999-56254-6225.001.TK4.EQUIP
PROJECT NAME Naval Weapons Station-Seal Beach, Site 70
LOCATION Naval Weapons Station-Seal Beach
DRILLING METHOD CME 75 Hollow Stem Auger
SAMPLING METHOD 5' CA-Modified Split Spoon
GROUND SURFACE ELEVATION (FT MSL)
TOP OF CASING ELEVATION (FT MSL)
LOGGED BY Kristeen Bennett
REMARKS

BORING/WELL NUMBER PMW7
DATE DRILLED 3/27/08
CASING TYPE/DIAMETER 4" Schedule 40 PVC
SCREEN TYPE/SLOT 4" PVC 0.010 Slot
GRAVEL PACK TYPE #2/16 Lapis Lustre Sand
GROUT TYPE/QUANTITY Neat Cement Grout / Medium Bentonite Chips
STATIC WATER LEVEL (FT BELOW TOC)
GROUND WATER ELEVATION (FT MSL)

PID (ppm)	RECOVERY (inches)	DEPTH (feet bgs)	U.S.C.S.	GRAPHIC LOG	LITHOLOGIC DESCRIPTION	CONTACT DEPTH
					4" Cored asphalt (18" diam.).	
			SM GM		0-4: GRAVELLY SILTY SAND: Olive-brown (2.5Y 4/3); subangular to subrounded, poorly graded sand; medium to coarse, subangular, poorly graded gravel; micaceous silt; moist.	
						4.0
			CL		4-5: SLIGHTLY SILTY CLAY: Black (2.5Y5/1); micaceous silt; moderately stiff, medium plasticity clay; moist	5.0
	42"/60"	5			5-10: Similar to above with color change to very dark grayish brown (2.5Y3/2) with depth.	
0.0/0.0			CL			
0.0/0.0						
	42"/60"	10			10-14.5: Similar to above with color change to olive brown (2.5Y4/4) at base; trace fine to medium, subangular, poorly graded gravel from 13-14.5'.	10.0
			CL			
						14.5
			CL SC		14.5-15: SANDY CLAY: Dark yellowish brown (10YR4/4); trace, subrounded, well graded sand; micaceous silt; stiff, medium plasticity clay; moist, iron oxide staining and "balls" organic-rich clay.	15.0
0.7/0.1	58"/60"	15			15-20: Similar to above with no "balls" of clay; alternating bands of dark yellowish brown/olive brown; moist	
			CL SC			
						20.0
4.6/0.1	20"/60"	20			20-23: Similar to above with increasing sand content.	
			CL SC			
						23.0
			SM		23-25: SLIGHTLY CLAYEY SILTY SAND; Yellowish brown (10YR 5/4); fine to medium, well graded, subrounded sand; micaceous silt; soft, low plasticity clay; wet.	
97.3/0.1	24"/60"	25			25-30: SLIGHTLY SILTY SAND: Olive brown (10YR 4/4); medium, subrounded, well graded sand; minor micaceous silt; wet.	25.0
			SW			
		30				30.0

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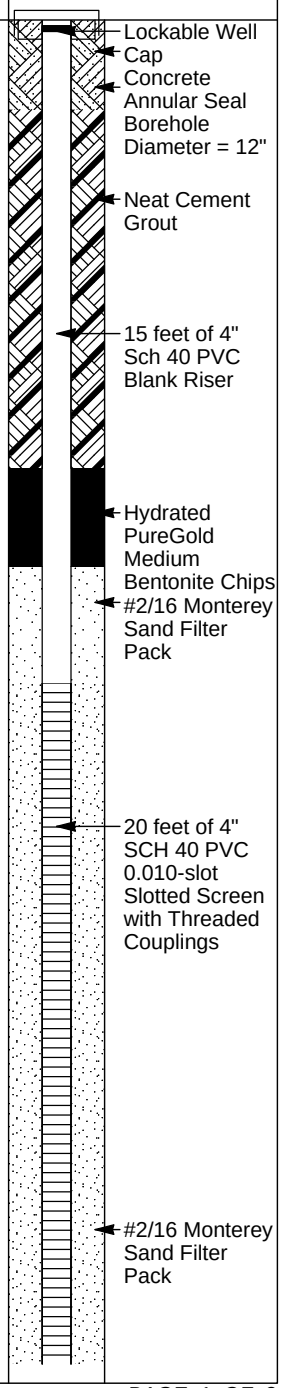
WELL DIAGRAM



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CDM
111 Academy, Suite 150
Irvine, CA 92617
Phone: (949) 752-5452
Fax: (949) 725-3907

BORING/WELL CONSTRUCTION LOG

PROJECT NUMBER 50999-56254-6225.001.TK4.EQUIP **BORING/WELL NUMBER** PMW7

PROJECT NAME Naval Weapons Station-Seal Beach, Site 70 **DATE DRILLED** 3/27/08

Continued from Previous Page

PID (ppm)	RECOVERY (inches)	DEPTH (feet bgs)	U.S.C.S.	GRAPHIC LOG	LITHOLOGIC DESCRIPTION	CONTACT DEPTH	WELL DIAGRAM
140.0/0.1	30"/60"		SW		30-33: Similar to above; wet.		#2/16 Monterey Sand Filter Pack
			ML		33-33.5: SILT: Olive (5Y4/3); laminated micaceous silt; moist	33.0 33.5	
			CL ML		33.5-34.5: SILTY CLAY: Olive (5Y /4); laminated micaceous silt and stiff, high plasticity clay; moist	34.5 35.0	
152/0.2		35	ML		34.5-35: SLIGHTLY SANDY SILT: Olive (5Y 4/4); fine, subrounded, well graded sand; laminated micaceous silt; moist to wet. Total Depth of Boring = 35.5 ft bgs.		Threaded SCH 40 PVC Bottom Cap
		40					
		45					
		50					
		55					
		60					

SEALBEACH SEALBEACH.GPJ NEWGINT.GDT 4/28/08

CDM
111 Academy, Suite 150
Irvine, CA 92617
Phone: (949) 752-5452
Fax: (949) 725-3907

BORING/WELL CONSTRUCTION LOG

PROJECT NUMBER 50999-56254-6225.001.TK4.EQUIP
PROJECT NAME Naval Weapons Station-Seal Beach, Site 70
LOCATION Naval Weapons Station-Seal Beach
DRILLING METHOD CME 75 Hollow Stem Auger
SAMPLING METHOD 5' CA-Modified Split Spoon
GROUND SURFACE ELEVATION (FT MSL)
TOP OF CASING ELEVATION (FT MSL)
LOGGED BY Kristeen Bennett
REMARKS

BORING/WELL NUMBER PMW8
DATE DRILLED 3/26/08
CASING TYPE/DIAMETER 4" Schedule 40 PVC
SCREEN TYPE/SLOT 4" PVC 0.010 Slot
GRAVEL PACK TYPE #2/16 Lapis Lustre Sand
GROUT TYPE/QUANTITY Neat Cement Grout / Medium Bentonite Chips
STATIC WATER LEVEL (FT BELOW TOC)
GROUND WATER ELEVATION (FT MSL)

PID (ppm)	RECOVERY (inches)	DEPTH (feet bgs)	U.S.C.S.	LITHOLOGIC DESCRIPTION	CONTACT DEPTH
				4" Cored asphalt (18" diam.).	
			SM	0-4: GRAVELLY SILTY SAND: Olive-brown (2.5Y 4/3); fine to coarse, subangular to subrounded, poorly graded sand; medium to coarse, poorly graded gravel; micaceous silt; moist.	
					4.0
			CL	4-5: SLIGHTLY SILTY CLAY: Black (2.5Y2.5/1); micaceous silt; medium stiff, medium plastic clay; moist.	5.0
	35"/60"	5		5-10: Similar to above with color change to dark olive gray (5Y3/2) with increasing depth.	
3.2/0.0			CL		
1.9/0.0					
4.0/0.0	48"/60"	10		10-14: Similar to above.	10.0
			CL		
9.9/0.0					14.0
			CL	14-15: SLIGHTLY SANDY CLAY: Dark yellowish brown (10YR4/4); fine, subrounded, well graded sand; stiff, low plasticity clay; trace micaceous silt; moist; some iron oxide staining.	15.0
3.9/0.0	52"/60"	15	CL	15-18: Similar to above, organic clay balls from 15 to 15.25'.	
3.5/0.0					18.0
			CL	18-20: Similar to above with no iron oxide staining.	
		20			20.0
12.7/0.0	30"/60"		SC	20-22: CLAYEY SAND: Dark olive gray (5Y3/2); fine to medium, subrounded, well graded sand; soft, medium plasticity clay; trace micaceous silt; wet.	22.0
22.5/0.0			SC	22-23: Similar to above with decreasing clay content.	23.0
			SM	23-25: SLIGHTLY CLAYEY SILTY SAND: Olive gray (5Y4/2); fine to medium, subrounded, well graded sand; micaceous silt; trace clay; wet.	
63.2/0.0					25.0
	30"/60"	25		25-29: Similar to above.	
55.3/0.0			SM		
					29.0
			SM	29-30: Similar to above with increasing silt content.	30.0
		30			

Continued Next Page

WELL DIAGRAM
- Lockable Well Cap
- Concrete Annular Seal
- Neat Cement Grout
- 15 feet of 4" Sch 40 PVC Blank Riser
- Borehole Diameter = 12"
- Hydrated PureGold Medium Bentonite Chips
- #2/16 Monterey Sand Filter Pack
- 20 feet of 4" SCH 40 PVC 0.010-slot Slotted Screen with Threaded Couplings
- #2/16 Monterey Sand Filter Pack

SEALBEACH SEALBEACH.GPJ NEWGINT.GDT 4/28/08

CDM
111 Academy, Suite 150
Irvine, CA 92617
Phone: (949) 752-5452
Fax: (949) 725-3907

BORING/WELL CONSTRUCTION LOG

PROJECT NUMBER 50999-56254-6225.001.TK4.EQUIP **BORING/WELL NUMBER** PMW8

PROJECT NAME Naval Weapons Station-Seal Beach, Site 70 **DATE DRILLED** 3/26/08

Continued from Previous Page

PID (ppm)	RECOVERY (inches)	DEPTH (feet bgs)	U.S.C.S.	GRAPHIC LOG	LITHOLOGIC DESCRIPTION	CONTACT DEPTH	WELL DIAGRAM
110/0.0	20"/60"		SM		30-32: SILTY SAND: Olive gray (5Y4/2.5); fine to medium, subrounded, well graded, sand; micaceous silt; wet.		#2/16 Monterey Sand Filter Pack
						32.0	
18.3/0.0					32-34.5: SLIGHTLY SANDY SILT: Light olive brown (2.5Y5/3); fine, subrounded, well graded sand; laminated micaceous silt; moist.		
166/0.0			ML SM				
						34.5	
			ML		34.5-35: Similar to above with increasing sand content	35.0	
116/0.0		35	SM		Total Depth of Boring = 35.5 ft bgs.		Threaded SCH 40 PVC Bottom Cap
		40					
		45					
		50					
		55					
		60					

SEALBEACH SEALBEACH.GPJ NEWGINT.GDT 4/28/08

Appendix E.4
Well Development Forms

Well No.: AEW1	Site: Seal Beach	Date: 9/20/07
Client:	Project Number:	
Well Casing Diameter (inches): 4"	Well Casing Material: (PVC) SS Other:	
Well Headspace: PID (ppm): 0.0		
Samplers: Chad Marvin with CDM	~~with Blaine Tech~~	
Total Depth of Well (feet): 35.0	2" - 0.16	
Depth to Water (feet): 17.27	(X) 4" - 0.65 Gal/ft. = 11.52 (X) 3 =	Minimum purge volume (gallons)
Water Column Height (feet): 17.73	6" - 1.47	
Well Reference Point:	"-	

PURGE METHOD: Submersible pump [X] Bladder pump [ ] Disposable ba[ ]	
Pump Make/Model: 2" Grundfos Rediflo	Depth of pump intake (feet):
Purge equipment decontaminated? Y [X] N [ ]	Container type: 55 gallon Drum
Purge/decon water containerized? Y [X] N [ ]	Volume: Bailed = 25 gallons Pumped = 740 gallons

Start Time: 0950 Flow Rate:

Time	Gallons	Temp. (°C °F)	pH	Conductivity (µmhos/cm)	Turbidity (NTUs)	DO (mg/L)	ORP (mV)	DTW (ft TOC)	Comments
1011	≈3	22.54	6.54	4739	>1000	3.99	193.6		Swab & Bail
1019	≈8	22.49	6.50	5076	>1000	3.52	162.8		"
1027	≈20	22.67	6.53	5414	>1000	4.22	163.5		"
1036	≈25	22.59	6.60	5696	>1000	4.42	162.5		"
1045	—	Begin to Pump well		—	—	—	—	SWL 17.31	Pumping
1050	≈1.5gpm	23.28	6.38	5641	545	2.13	114.2	20.48	"
1055	≈20	23.41	6.40	5914	221	0.89	86.0	21.96	"
1100	≈30	23.36	6.40	6001	890	0.70	46.0	21.95	"
1105	≈1.7gpm	23.36	6.39	6009	695	0.69	49.2	21.96	"
1110	≈40	23.41	6.40	6117	122	0.66	27.2	21.97	"
1115	≈1.6gpm	23.43	6.40	6129	183	0.65	27.0	21.97	"
1120	≈60	23.38	6.39	6123	56.7	0.64	48.3	21.94	"
1125	≈1.7gpm	23.39	6.40	6160	45.7	0.64	60.4	22.11	"
1130	70	23.40	6.40	6156	52.0	0.66	63.8	22.10	"

Chemets DO (mg/L):

Sample Analyses: →	Analyzed ?	EPA Method	Container Type/Volume	Preservative
Sample Collection Method: ↙				

Pump: [X] Flow Rate:	Sample ID:	Sample Time:
Bailer: [X] Type: ~~disposable~~ stainless steel	Duplicate ID:	Sample Time:
Other: [ ] Desc.:	Equip. blank ID:	Sample Time:

CDM MONITORING WELL PURGE AND SAMPLING FORM

Well No.: AEW1	Site: Seal Beach	Date: 9/21/07
Client:	Project Number:	
Well Casing Diameter (inches):	Well Casing Material: PVC SS Other:	
Well Headspace: PID (ppm):		
Samplers: with CDM		with Blaine Tech

Total Depth of Well (feet): _____ 2" - 0.16

Depth to Water (feet): _____ (X) 4" - 0.65 Gal/ft. = _____ (X) 3 = _____

Water Column Height (feet): _____ 6" - 1.47 ← Minimum purge volume (gallons)

Well Reference Point: ___" - ____

PURGE METHOD: Submersible pump ☐ Bladder pump ☐ Disposable ba☐

Pump Make/Model: 2" Grundfos Rediflo	Depth of pump intake (feet):
Purge equipment decontaminated? Y ☐ N ☐	Container type:
Purge/decon water containerized? Y ☐ N ☐	Volume:

Start Time: _____ Flow Rate: _____

Time	Gallons	Temp. (°C)/°F)	pH	Conductivity (µmhos/cm)	Turbidity (NTUs)	DO (mg/L)	ORP (mV)	DTW (ft TOC)	Comments
1140	≈ 1.5gpm	23.94	6.44	6230	176	1.50	87.6	20.54	Pumping
1200	≈ 2gpm	23.61	6.39	6110	189	0.71	93.6	22.13	Pump & Surge
1220	≈ 2gpm	23.53	6.40	6115	148	1.07	174.2	23.01	"
1231	≈ 90	23.21	6.38	5315	85.4	1.08	1125	23.41	"
1246	≈ 2gpm	23.26	6.39	5830	119	1.04	105.4	23.91	"
1250	≈ 2gpm	23.19	6.42	6641	183	0.84	108.7	22.4	After surge
1300	≈ 150	23.34	6.40	6389	83.2	0.71	102.6	24.11	"
1308	≈ 2gpm	23.33	6.43	7180	290	0.56	115.1	21.38	After surge
1320	≈ 2gpm	23.33	6.40	6451	104	0.76	105.2	24.27	During
1326	≈ 195	23.37	6.41	6287	103	1.05	97.9	20.63	After surge
1341	≈ 2gpm	23.40	6.40	6416	65.3	0.75	93.6	24.23	During
1345	≈ 220	23.69	6.46	6753	89.2	2.32	111.6	20.62	After surge
1400	≈ 2gpm	23.41	6.40	6355	125	0.96	110.4	23.92	During
1430	≈ 235	23.42	6.40	6467	45.2	0.85	112.2	24.18	During
1455	≈ 270	23.40	6.39	6415	39.9	0.86	115.2	24.04	During

Chemets DO (mg/L): _____

Sample Analyses: →	Analyzed ?	EPA Method	Container Type/Volume	Preservative
Sample Collection Method: ↙				

Pump: ☐ Flow Rate:	Sample ID:	Sample Time:
Bailer: ☐ Type: disposable	Duplicate ID:	Sample Time:
Other: ☐ Desc.:	Equip. blank ID:	Sample Time:

CDM MONITORING WELL PURGE AND SAMPLING FORM

Well No.: AEW1	Site: Seal Beach	Date:
Client:	Project Number:	
Well Casing Diameter (inches):	Well Casing Material: PVC SS Other:	
Well Headspace: PID (ppm):		
Samplers: with CDM		with Blaine Tech

Total Depth of Well (feet): _____ 2" - 0.16

Depth to Water (feet): _____ (X) 4" - 0.65 Gal/ft. = _____ (X) 3 = _____ Minimum purge volume (gallons)

Water Column Height (feet): _____ 6" - 1.47

Well Reference Point: __" - ____

PURGE METHOD: Submersible pump ☐ Bladder pump ☐ Disposable ba☐

Pump Make/Model: 2" Grundfos Rediflo	Depth of pump intake (feet):
Purge equipment decontaminated? Y ☐ N ☐	Container type:
Purge/decon water containerized? Y ☐ N ☐	Volume:

Start Time: _____ Flow Rate: _____

Time	Gallons	Temp. (°C/°F)	pH	Conductivity (µmhos/cm)	Turbidity (NTUs)	DO (mg/L)	ORP (mV)	DTW (ft TOC)	Comments
1507	≈2gpm	23.52	6.41	6203	54.2	1.07	125.3	22.22	After surge
1520	≈2gpm	23.40	6.41	6725	42.7	0.99	118.1	24.12	During
1538	≈320	23.43	6.39	6277	95.6	1.58	105.9	23.47	During
1559	≈335	23.44	6.39	6535	59.4	0.90	100.6	23.68	During
1600	—	stop	Pumping	for	Today	—	—	—	—
9/24 1420	—	Begin	to	pump	—	—	—	STWL 18.73 16.88'	—
1425	≈1.5gpm	23.39	6.35	5239	42.7	2.53	151.6	19.77	During
1445	≈40 +335	23.30	6.39	5883	58.1	1.13	126.5	22.83	During
1448	≈2gpm	23.68	6.51	5526	244	3.30	138.1	19.17	After surge
1500	≈2gpm	23.41	6.42	6013	41.6	1.00	120.5	20.25	During
1512	≈2 415 gpm	23.45	6.42	6085	21.2	0.99	120.6	23.29	During
1520	415	23.77	6.46	7014	36.8	0.82	127.3	21.02	After surge
1530	≈2gpm	23.31	6.40	6272	21.5	0.77	121.0	23.88	During
1545	≈460	23.32	6.41	6188	26.8	0.85	115.4	23.83	During
1600	≈475	23.31	6.41	6076	15.6	0.87	118.0	23.29	During
1600	—	Stop	pumping	for	today	—	—	—	—

Chemets DO (mg/L): _____

Sample Analyses: →	Analyzed ?	EPA Method	Container Type/Volume	Preservative
Sample Collection Method: ↙				

Pump: ☐ Flow Rate:	Sample ID:	Sample Time:
Bailer: ☐ Type: disposable	Duplicate ID:	Sample Time:
Other: ☐ Desc.:	Equip. blank ID:	Sample Time:

CDM

MONITORING WELL PURGE AND SAMPLING FORM

Well No.: AEW1	Site: Seal Beach NWS	Date: 9/25/07

Time	Gallons	Temp. (°C/°F)	pH	Conductivity (µmhos/cm)	Turbidity (NTUs)	DO (mg/L)	ORP (mV)	DTW (ft TOC)	Comments
7:50	—	Begin pumping						16.95	
7:51	~2 gpm	23.10	6.44	5245	24.9	1.91	94.1	19.52	After start
7:59	25 gal	23.23	6.44	5971	33.8	1.04	240.6	22.40	During pumping
8:16	50 gal	23.31	6.44	6083	44.6	1.07	155.1	22.48	During
8:36	67 gal	23.30	6.43	6046	35.3	1.07	134.7	22.00	During
8:46	75 gal	23.26	6.43	5900	11.1	0.88	138.2	20.63	After surge
8:53	84 gal	23.32	6.42	6079	41.2	1.16	136.1	22.46	During
9:06	100 gal	23.32	6.38	6060	21.5	0.99	109.8	22.20	During
9:21	117 gal	23.30	6.43	6598	21.5	0.80	129.7	22.65	During
9:35	125 gal	23.28	6.45	6053	14.1	0.96	130.7	21.21	After surge
9:42	140 gal	23.34	6.42	6100	27.1	1.33	126.7	23.00	During
9:55	150 gal	23.32	6.43	6016	11.5	0.77	129.5	23.66	During
10:15	180 gal	23.33	6.44	6451	15.7	1.27	127.3	24.25	During
10:24	180 gal	23.53	6.52	7568	11.8	1.52	125.0	20.65	After surge
10:30	195 gal	23.33	6.44	6070	19.0	1.03	120.7	21.47	During
10:46	215 gal	23.37	6.44	6256	17.7	0.99	118.7	23.20 (19.17)	During
11:35								Resume pumping	
11:37	Begin pumping at 200 H_2 until 50 gal extracted								
11:39	≈215 gal	23.23	6.43	6122	9.51	1.35	132.3	19.30	
11:45								22.11	
11:47	≈232 (219) gal	23.36	6.42	6103	28.7	1.65	192.4	[illegible]	
11:50								23.15	
11:55	≈249 (234) gal	23.36	6.44	6495	11.9	0.99	134.9	23.16	
12:00								23.16	
12:04	≈265 (250) gal	23.36	6.45	6553	10.2	1.15	130.5	23.16	
—	End 50 gal Test								
End	AEW1 Development								
Total	740 gal								

Well No.: AEW 2	Site: Seal Beach	Date: 9/20/07
Client:	Project Number:	
Well Casing Diameter (inches): 4"	Well Casing Material: (PVC) SS Other:	
Well Headspace: PID (ppm): 0.0		
Samplers: Chad Marvin with CDM	~~with Blaine Tech~~	
Total Depth of Well (feet): 35.0	2" - 0.16	
Depth to Water (feet): 16.45	(X) 4" - 0.65 Gal/ft. = 12.06 (X) 3 =	Minimum purge volume (gallons)
Water Column Height (feet): 18.55	6" - 1.47	
Well Reference Point:	"-	

PURGE METHOD: Submersible pump [X]	Bladder pump [ ] Disposable ba[ ]
Pump Make/Model: 2" Grundfos Rediflo	Depth of pump intake (feet): 34' BGS
Purge equipment decontaminated? Y [X] N [ ]	Container type: 55 gallon drum
Purge/decon water containerized? Y [X] N [ ]	Volume: Bailed = 41 gallons Pumped = 1120 gallons

Start Time: 14:25 Flow Rate:

Time	Gallons	Temp. (°C/°F)	pH	Conductivity (µmhos/cm)	Turbidity (NTUs)	DO (mg/L)	ORP (mV)	DTW (ft TOC)	Comments
1440	≈ 9	23.69	6.54	6601	>1000	3.32	188.2		swab & Bail
1452	≈ 13	22.98	6.59	6740	>1000	3.55	116.1		"
1456	≈ 16	22.71	6.61	7346	>1000	4.01	112.2		"
1502	≈ 19	22.84	6.56	7793	>1000	3.67	118.5		"
1508	≈ 25	22.69	6.62	8360	>1000	4.48	139.2		"
1515	≈ 29	22.52	6.56	8736	>1000	4.06	142.6		"
1519	≈ 34	22.44	6.58	8794	>1000	4.18	134.3		"
1530	≈ 41	22.43	6.62	8854	>1000	4.75	148.6		"
9/21									
0840	Begin to	Pump	well.					16.32	
0845	≈ 2gpm	23.00	6.49	8857	81.2	2.34	122.5	19.26	pumping
0854	≈ 30	23.02	6.48	8800	208	1.78	115.2	19.96	"
0900	≈ 2.5gpm	23.03	6.46	9207	178	1.35	113.8	21.04	"
0905	≈ 50	22.99	6.42	9744	123	0.48	113.3	21.42	"
0910	≈ 60	22.96	6.42	9733	176	0.37	112.0	21.52	

Chemets DO (mg/L):

Sample Analyses: →	Analyzed ?	EPA Method	Container Type/Volume	Preservative
Sample Collection Method: ↙				

Pump: [X] Flow Rate:	Sample ID:	Sample Time:
Bailer: [X] Type: ~~disposable~~ stainless steel	Duplicate ID:	Sample Time:
Other: [ ] Desc.:	Equip. blank ID:	Sample Time:

CDM

MONITORING WELL PURGE AND SAMPLING FORM

Well No.: AEW2	Site:	Date: 9/21/07
Client:	Project Number:	
Well Casing Diameter (inches):	Well Casing Material: PVC SS Other:	
Well Headspace: PID (ppm):		
Samplers: with CDM		with Blaine Tech

Total Depth of Well (feet): _____ 2" - 0.16

Depth to Water (feet): _____ (X) 4" - 0.65 Gal/ft. = _____ (X) 3 = _____ Minimum purge volume (gallons)

Water Column Height (feet): _____ 6" - 1.47

Well Reference Point: __" - ____

PURGE METHOD: Submersible pump ☐ Bladder pump ☐ Disposable ba ☐

Pump Make/Model: 2" Grundfos Rediflo	Depth of pump intake (feet):
Purge equipment decontaminated? Y ☐ N ☐	Container type:
Purge/decon water containerized? Y ☐ N ☐	Volume:

Start Time: _____ Flow Rate: _____

Time	Gallons	Temp. (°C/°F)	pH	Conductivity (µmhos/cm)	Turbidity (NTUs)	DO (mg/L)	ORP (mV)	DTW (ft TOC)	Comments
0915	≈ 2 gpm	22.95	6.42	9792	130.2	0.34	111.7	21.62	Pumping
0925	≈85	22.96	6.42	9822	51.3	0.37	111.0	21.76	"
0935	≈105	22.95	6.42	9826	86.2	0.56	110.1	22.03	"
0950	≈ 2 gpm	22.93	6.43	9776	280.1	0.77	111.4	22.19	"
1000	≈ 140	22.94	6.42	9787	107.2	0.83	113.5	21.27	"
1010	≈ 1.5gpm	22.94	6.42	9696	29.8	0.63	115.2	21.28	"
1020	≈175	22.94	6.41	9698	10.4	0.45	115.9	21.34	"
1030	≈ 1.5gpm	22.94	6.41	9705	6.86	0.39	116.0	21.27	"
1035	≈200	22.96	6.42	9698	5.81	0.38	115.2	21.31	"
1035		Stop Pumping well							
								STWL 16.15	
9/25 12:55	Begin pumping @ 200 Hz								
12:57		22.96	6.56	6200	76.2	1.81	88.7	18.15	During pumping
13:05	≈10 gal	23.13	6.53	7236	59.6	1.32	112.5	19.00	During
13:20	≈25 gal				37.9			19.00	During

Chemets DO (mg/L): _____

Sample Analyses: →	Analyzed ?	EPA Method	Container Type/Volume	Preservative
Sample Collection Method: ↙				

Pump: ☐ Flow Rate:	Sample ID:	Sample Time:
Bailer: ☐ Type: disposable	Duplicate ID:	Sample Time:
Other: ☐ Desc.:	Equip. blank ID:	Sample Time:

CDM MONITORING WELL PURGE AND SAMPLING FORM

Well No.: AEW2 | Site: Seal Beach NWS | Date: 9/25/07

Time	Gallons	Temp. (°C/°F)	pH	Conductivity (µmhos/cm)	Turbidity (NTUs)	DO (mg/L)	ORP (mV)	DTW (ft TOC)	Comments
13:29	≈30 gal	23.02	6.47	9031	50.2	0.99	128.8	19.70	After surge
13:35	(Duo) ≈40 gal	23.05	6.47	9139	74.7	1.02	126.0	20.57	During
13:52	≈65 gal	23.03	6.46	9487	53.8	0.90	125.0	20.65	During
14:07	≈82 gal	23.08	6.46	9518	46.6	0.82	121.3	20.86	During
14:21	≈105 gal	23.07	6.45	9723	36.8	0.45	121.9	20.83	During
14:29	Begin	50	gal	Test	@ 200	Hz			
14:29								12.17	
14:35	≈120 gal (15)	23.01	6.45	9806	24.6	0.48	121.8	20.05	
14:40								20.68	
14:45	≈135 gal (30)	23.05	6.46	9707	36.5	0.47	119.0	21.03	
14:50								21.20	
14:57	≈170 gal (50)	23.05	6.45	9854	123	0.12	109.6	21.50	Possible error on tape
	End Test								
15:04	Resume pumping								
15:12	187 gal	23.02	6.45	9954	57.6	0.43	109.3	20.83	During
15:27	200 gal	23.03	6.45	9852	19.3	0.69	119.3	20.91	During
15:36	205 gal	23.28	6.50	9551	7.38	0.60	135.2	19.25	After surge
15:45	220 gal	23.03	6.45	9812	14.0	0.72	122.0	20.78	During
	End pumping for today								
9/26	Begin pumping to flush well - 220 gallons previously purged								
0744	~220	22.87	6.46	9601	15.9	1.20	79.1		Begin purge
0754	~240	23.04	6.52	8559	61.0	1.39	158.8	20.66	23.32
0804	~255	23.01	6.48	9593	10.5	0.70	142.3	21.22	
0814	~270	22.98	7.00	9287	117	0.92	135.2	16.20	purge paused to reduce
0826	~270	23.02	6.50	9621	38.8	0.50	117.2	16.20	purge resumed
0836	~290	23.06	6.48	9653	43.2	1.10	154.7	22.1	
0839	Pump stopped								
0844	300	22.98	6.49	9741	13.8	0.56	142.6	19.8	Pumping resumed
0854	320	23.00	6.48	9678	18.2	0.93	125.4	21.7	
0856	325								Purge paused
0906	325	22.95	6.52	9673	10.8	1.05	137.5	19.25	Resume pumping
0916	345	22.97	6.48	9686	23.7	1.11	142.0	21.00	pause 0918
0921	350	22.93	6.49	9733	10.9	0.76	138.2	20.30	Resume
0931	365	23.02	6.48	9746	10.9	0.74	124.0	21.08	pause -0933
0936	370	22.90	6.47	9833	14.4	0.42	125.8	20.65	STOP 0941
0957	370	22.95	6.60	9725	43.7	4.72	123.1	18.30	Resume
1007	390	23.04	6.48	9827	20.8	1.26	163.2	20.65	pause 1009
1012	395	22.98	6.49	9724	10.4	0.71	157.5		
1024	415	23.01	6.48	9608	56.1	2.76	133.9	21.6	Resume 1028

Well No.: AEW2 | Site: | Date: 9/26/07

Time	Gallons	Temp. (°C/°F)	pH	Conductivity (µmhos/cm)	Turbidity (NTUs)	DO (mg/L)	ORP (mV)	DTW (ft TOC)	Comments
1057	7	22.96	6.48	9849	41.5	0.34	130.4	19.37	
1107	25	23.10	6.48	9713	26.5	1.09	215.0	20.90	
1117	50	23.09	6.47	9846	47.5	0.30	140.7	21.46	
1127	70	22.99	6.47	99.3	98.4	0.18	117.8	22.41	
1137	85	23.08	6.48	9917	139	0.60	95.8	22.24	
1147	100	23.09	6.48	9892	184	0.69	96.1	22.38	
1157	120	23.08	6.48	9875	65.5	0.67	96.8	22.54	
1207	140	22.97	6.48	9898	392	0.72	99.1	22.98	
1217	160	23.13	6.48	9801	72.3	1.01	107.5	23.19	
1227	180	23.14	6.47	9886	21.4	0.72	111.1	22.56	
1237	200	23.16	6.47	9800	8.27	0.77	112.4	22.52	
1247	220	23.05	6.47	9896	9.17	0.91	114.0	23.03	
1257	240	23.14	6.48	9892	26.2	0.71	113.6	23.02	
1307	260	23.15	6.48	9921	50.7	0.63	114.4	23.02	
1317	280	23.04	6.47	9880	6.04	0.77	114.1	23.16	
1327	300	23.08	6.48	9886	7.46	0.69	113.6	23.01	
1337	320	23.06	6.48	9897	3.76	0.93	114.9	22.84	
1347	340	23.13	6.48	9905	11.2	0.68	112.7	23.33	
1357	360	23.12	6.48	99.05	4.40	0.72	112.1	23.10	
1410	380	23.10	6.49	9836	2.20	0.72	111.0	23.06	Pump stopped
1420								15.95	Static
1430 1435	385	23.50	6.53	9832	29.3	1.81	108.6	19.65	Resume Pumping @ 250ml/min 1430
1440	405	23.28	6.48	9820	15.3	1.19	194.3	20.88	
1450	425	23.21	6.47	9711	20.6	0.52	145.6	21.31	
1500	445	23.14	6.46	9819	31.3	0.36	135.0	21.91	Pump stopped 1502
1510	460	23.10	6.50	9763	14.7	0.28	135.8	16.7	Begin Pumping
1520	470	23.12	6.46	9863	18.0	0.89	129.1	21.17	
1530	490	23.08	6.47	9795		0.51	128.5	21.93	
1540	510	23.03	6.47	9877		0.38	121.4	22.05	Pumping Stopped

Pg 1 of 2
2.08 - wellbox to toc

Well No.: AIW1	Site: Seal Beach	Date: 9/27/07
Client:	Project Number:	
Well Casing Diameter (inches): 4"	Well Casing Material: PVC SS Other:	
Well Headspace: 0.0 PID (ppm):		
Samplers: — with CDM		with Blaine Tech

Total Depth of Well (feet): ~~35~~ 31.12 2" - 0.16

Depth to Water (feet): 17.33 (X) 4" - 0.65 Gal/ft. = 8.96 (X) 3 = _____

Water Column Height (feet): 13.79 6" - 1.47 ← Minimum purge volume (gallons)

Well Reference Point: TOC __" - ____

PURGE METHOD: Submersible pump ☑	Bladder pump ☐ Disposable ba ☐
Pump Make/Model: 2" Grundfos Rediflo	Depth of pump intake (feet):
Purge equipment decontaminated? Y ☑ N ☐	Container type: Baker tank
Purge/decon water containerized? Y ☑ N ☐	Volume: Bailed = 20 gallons Pumped = 325 gallons

Start Time: 0858 Flow Rate: ~~0.5~~ 0.5 gpm

Time	Gallons	Temp. (°C/°F)	pH	Conductivity (µmhos/cm)	Turbidity (NTUs)	DO (mg/L)	ORP (mV)	DTW (ft TOC)	Comments
0819	10	22.35	7.43	16662	>999	6.77	142.5	—	Swab + bail
0823	20	22.07	7.43	17438	>999	5.93	135.7	—	
~~0858~~ 0916	35	22.25	7.15	20017	>999	1.55	55.7	19.97	Begin pumping
0920	40	22.50	7.15	19975	>999	1.99	54.1	20.95	
0930	45	22.45	7.16	20041	1000	2.62	58.3	21.23	150hz
0940	55	21.88	7.16	19586	1000	3.78	58.1	24.12	
0950	65	22.00	7.15	19892	1000	3.10	51.3	25.58	Fine sand in purge
~~0960~~ 1000	75	21.79	7.10	19951	997	1.77	39.9	26.75	water
1010	85	21.59	7.09	20289	221	1.44	48.8	27.12	"
1020	95	21.31	7.09	20329	217	2.13	56.1	27.68	
1030	105	21.27	7.09	20423	72.8	2.08	60.1	27.75	Purging paused
1100	105	22.74	7.13	20365	115	2.20	95.5	18.72	Resume @ 150hz
1110	115	22.88	7.09	19501	590	3.08	56.8	22.63	
1120	125	22.73	7.10	19255	1000	2.91	18.2	25.58	

Chemets DO (mg/L): —

	Analyzed ?	EPA Method	Container Type/Volume	Preservative
Sample Analyses: →				
Sample Collection Method: ↙				

Pump: ☐ Flow Rate:	Sample ID:	Sample Time:
Bailer: ☐ Type: disposable	Duplicate ID:	Sample Time:
Other: ☐ Desc.:	Equip. blank ID:	Sample Time:

CDM MONITORING WELL PURGE AND SAMPLING FORM

Well No.: AZW1 | Site: | Date:

Time	Gallons	Temp. (°C/°F)	pH	Conductivity (µmhos/cm)	Turbidity (NTUs)	DO (mg/L)	ORP (mV)	DTW (ft TOC)	Comments
1130	135	23.05	7.07	19867	76.3	2.42	45.9	28.32	Still has sand
1140	145	22.97	7.07	19865	31.2	2.14	43.3	28.22	"
1150	155	23.11	7.06	19905	13.1	2.15	29.8	28.60	"
1200	165	23.10	7.06	19910	16.5	2.23	34.1	28.53	Pause purging
1230	165	22.70	7.08	20520	26.4	0.66	41.6	19.02	Resume @ 150Hz
1240	175	22.80	7.06	19874	26.5	2.17	46.4	22.91	
1250	185	23.01	7.06	19430	52.6	3.61	75.7	21.06	
~~1300~~ 1255	195	23.00	7.05	19685	26.3	2.24	53.2	27.37	
~~1310~~ 1300	205	22.97	7.05	19837	15.5	1.88	47.6	28.08	
1320	215	22.96	7.06	19863	36.1	2.20	57.9	28.58	
1330	225	23.00	7.06	19891	29.2	2.13	56.8	28.27	Purging paused
1400	225	22.64	7.07	20530	10.8	0.75	31.2	19.08	Resume purge
1410	235	22.94	7.08	19928	23.5	3.87	65.0	24.09	
1420	245	22.99	7.07	19953	30.3	3.34	79.2	26.01	
1430	255	23.00	7.05	19694	12.4	2.21	66.8	26.95	
1440	265	23.03	7.06	19817	39.5	1.75	61.2	27.07	
1450	275	22.92	7.07	19847	15.9	1.83	54.3	27.98	
1500	285	22.54	7.07	20007	15.6	2.00	55.5	27.96	
1510	295	22.57	7.07	20030	10.0	2.10	56.8	28.14	
1520	305	22.66	7.07	19993	5.86	2.14	55.7	28.21	
1530	315	22.67	7.07	19989	6.14	2.08	55.3	28.34	
1540	325	22.68	7.07	19979	5.68	2.17	56.0	28.34	

Well No.: AIW2	Site: Seal Beach	Date: 9/28/07
Client:	Project Number:	
Well Casing Diameter (inches): 4"	Well Casing Material: (PVC) SS Other:	
Well Headspace: PID (ppm):	FID (ppm): N/A	
Samplers: Chad Marvin with CDM	~~with Blaine Tech~~	

Total Depth of Well (feet): 35 — 2" - 0.16
Depth to Water (feet): 14.99 (X) 4" - 0.65 Gal/ft. = 13.01 (X) 3 = _____
Water Column Height (feet): 20.01 — 6" - 1.47
Well Reference Point: **TOC** — __" - ___

↖ Minimum purge volume (gallons)

PURGE METHOD: Submersible pump [X] Bladder pump [ ] Disposable bailer [ ]

Pump Make/Model: 2" Grundfos Rediflo	Depth of pump intake (feet):
Purge equipment decontaminated? Y [X] N [ ]	Container type:
Purge/decon water containerized? Y [X] N [ ]	Volume: Bailed = ~~95~~ gallons Pumped = 410 gallons

Start Time: _____ Flow Rate: _____

Time	Gallons	Temp. (°C/°F)	pH	Conductivity (µmhos/cm)	Turbidity (NTUs)	DO (mg/L)	ORP (mV)	DTW (ft TOC)	Comments
0745		Begin to swab & Bail							
0805	5	21.93	7.62	5925	>1000	7.20	177.0		swab & bail
0815	13	21.30	7.56	6100	>1000	4.43	104.3	26.81	swab & bail
0835	30	21.62	7.58	6212	>1000	4.81	99.9	27.49	"
0850	40	Finished swab & Bail							
0925		Begin to Pump well						17.94	Pumping
0935	3/4 gpm	22.59	7.46	10580	>1000	5.82	93.1	18.99	Pumping
0950	1.5 gpm	22.65	7.31	9349	>1000	4.12	45.6	19.47	"
1000	1.75 gpm	22.39	7.23	10950	>1000	2.57	50.5	24.87	"
1010		stop Pumping to much sediment @ bottom							Removed ≈ 45 gal.
10/1 0755		Begin to swab & Bail							
0807		21.87	7.67	10899	>1000	6.75	246.3	stwl 15.23	swab & Bail
0840	45	21.71	7.69	16630	>1000	7.70	213.3		Swab & Bail
0845	55	Finished w/ swab & Bail							
1000		Begin to Pump Well						stwl 15.94	Pumping

Chemets DO (mg/L): _____

	Method	Container Type/Volume	Preservative
Sample Analyses: →			
Sample Collection Method: ↘			

Pump: [ ] Flow Rate:	Sample ID:	Sample Time:
Bailer: [ ] Type: disposable	Duplicate ID:	Sample Time:
Other: [ ] Desc.:	Equip. blank ID:	Sample Time:

CDM — MONITORING WELL PURGE AND SAMPLING FORM

Well No.: AIW2 | Site: Seal Beach | Date: 10/1/07

Time	Gallons (gpm/discharge)	Temp. (°C/°F)	pH	Conductivity (µmhos/cm)	Turbidity (NTUs)	DO (mg/L)	ORP (mV)	DTW (ft TOC)	Comments
1005	≈1.5 gpm	23.24	7.40	16196	868	5.30	44.5	19.68'	Pumping
1020	≈1.3 gpm	23.22	7.40	16301	399	5.19	50.7	19.86	"
1030	≈1.6 gpm	22.88	7.23	14296	232	2.99	60.1	23.42	"
1040	45 gal.	22.97	7.27	15295	147	3.09	56.7	27.28	"
1110	≈1.2 gpm	23.07	7.24	14172	120	3.88	66.9	22.03	"
1120	≈1.2 gpm	23.09	7.19	14469	107	2.65	70.6	24.72	"
1130	≈1.1 gpm	23.12	7.21	14573	7.35	2.76	78.4	25.24	30 mins of pumping 40 mins
1140	40 gal.	23.12	7.21	14485	5.99	2.93	78.0	25.99	Pumping
1200	≈1.1 gpm	23.14	7.20	14398	4.86	2.81	76.9	26.42	1Hr Pumping
1215	≈1.1 gpm	23.29	7.30	14780	36.2	4.06	74.8	16.74	Begin to pump
1230	≈1.1 gpm	23.27	7.18	13944	142	3.38	68.8	22.73	15 mins pumping
1245	≈1.1 gpm	23.20	7.18	14403	10.5	2.63	85.5	25.58	30 mins
1300	≈1.1 gpm	23.20	7.19	14455	6.58	2.68	86.4	26.57	45 mins
1315	≈145 gal	23.12	7.17	14506	10.10	2.94	86.3	22.27	5 mins
1330	≈1.1 gpm	23.18	7.16	14639	9.82	2.62	94.1	25.95	20 mins
1350	≈1.1 gpm	23.09	7.14	14672	10.1	3.21	92.9	22.38	5 mins
1400	≈1.1 gpm	23.24	7.13	14708	21.6	2.52	84.8	24.84	15 mins
1410	185 gal	23.19	7.15	14896	3.2	2.61	96.7	26.13	25 mins
1425	≈1.1 gpm	23.13	7.15	14928	6.3	2.81	85.8	22.01	5 mins
1435	≈1.1 gpm	23.13	7.12	14896	16.8	2.82	87.7	25.13	15 mins
1445	≈1.1 gpm	23.14	7.15	15170	4.9	2.56	95.4	26.48	25 mins
1505	≈1.1 gpm	22.87	7.13	15132	27.8	2.91	79.3	22.04	5 mins
1515	230 gal	23.05	7.12	15231	30.2	2.68	81.1	24.96	15 mins
1525	≈1.1 gpm	23.08	7.14	15149	4.7	2.69	86.7	26.57	25 mins
1545	≈1.1 gpm	22.98	7.15	15313	34.2	3.59	80.9	25.29	15 mins
1610	≈270 gal	22.97	7.14	15300	22.8	3.62	84.2	26.98	40 mins
1610	270 gal	—	Stop	Pumping	for	Today	—		—
10/2 0740	↓	Begin	to	Pump	well	1	—	STWL 15.26'	—
0745	≈1.1 gpm	22.66	7.44	19563	39.9	5.21	299.0	18.77	Pumping
0755	≈1.1 gpm	22.82	7.38	18287	41.7	4.99	182.7	21.84	15 mins
0810	≈1.1 gpm	22.75	7.19	16408	18.0	3.20	107.5	25.25	30 mins
0825	≈310 gal	22.67	7.17	16286	9.4	3.80	103.5	21.61	5 mins
0835	≈1.1 gpm	22.77	7.12	15995	12.9	3.41	98.4	25.03	15 mins
0845	≈1.1 gpm	22.82	7.15	16249	5.0	3.48	97.6	26.69	25 mins
0900	≈370 gal	22.80	7.17	16120	7.2	4.08	98.2	22.88	5 mins
0905	≈1.1 gpm	22.86	7.13	15981	6.9	3.62	97.3	25.07	10 mins
0920	≈1.1 gpm	22.91	7.14	16103	2.8	3.57	103.2	27.06	25 mins
0925	≈365 gal	—	Stop	Pumping	well	Developed	—		—

Well No.: AMW 1	Site: Seal Beach	Date: 10/2/07
Client:	Project Number:	
Well Casing Diameter (inches): 4"	Well Casing Material: (PVC) SS Other:	
Well Headspace: PID (ppm): 0.0	FID (ppm): N/A	
Samplers: Chad Martin with CDM	~~with Blaine Tech~~	

Total Depth of Well (feet): 35.10' 2" - 0.16
Depth to Water (feet): 18.88 (X) 4" - 0.65 Gal/ft. = 10.54 (X) 3 = _____ ← Minimum purge volume (gallons)
Water Column Height (feet): 16.22 6" - 1.47
Well Reference Point: **TOC** __" - ____

PURGE METHOD: Submersible pump [X] Bladder pump [ ] Disposable bailer [ ]

Pump Make/Model: 2" Grundfos Rediflo	Depth of pump intake (feet):
Purge equipment decontaminated? Y [X] N [ ]	Container type:
Purge/decon water containerized? Y [X] N [ ]	Volume: Bailed = 45 gallons Pumped = 300 gallons

Start Time: _____ Flow Rate: _____

Time	Gallons	Temp. (°C/°F)	pH	Conductivity (µmhos/cm)	Turbidity (NTUs)	DO (mg/L)	ORP (mV)	DTW (ft TOC)	Comments
0950	———	Begin	to surge	& Bail	———			STWL 18.88	———
1020	≈4	23.84	7.72	15982	>1000	5.32	128.4	———	swab & Bail
1030	≈30	22.90	7.77	15643	>1000	5.47	111.4	———	swab & Bail
1040	≈40	22.64	7.70	19098	>1000	4.65	83.7	———	"
1050	≈45	Finished w/	swab	& Bail	———				———
1100	———	Begin	To Pump well	———				20.61	Pumping
1110	~~2~~ 1gpm	23.84	7.52	17210	>1000	9.65	24.0	30.06	Pumping
1125	1gpm	23.54	7.46	18440	>1000	10.90	56.3	31.73	Pumping
1130	[redacted]	Stop	Pumping let	well Recover	———				———
1225	Resume	Pumping	———					STWL 25.26	———
1230	≈1 gpm	23.35	7.03	16203	784	6.40	74.7	27.02	Pumping
1245	≈1gpm	24.17	7.22	17279	402	7.65	69.7	29.52	20 mins
1300	≈0.8gpm	25.18	7.29	16977	87	7.72	63.2	31.36	35 mins
1310	≈0.7gpm	25.22	7.29	16526	71	8.14	66.6	31.70	45 mins
1340	≈0.9gpm	23.98	7.15	16214	>1000	10.60	39.7	29.45	10 mins

Chemets DO (mg/L): _____

	Method	Container Type/Volume	Preservative
Sample Analyses: →			
Sample Collection Method: ↘			

Pump: [ ] Flow Rate:	Sample ID:	Sample Time:
Bailer: [ ] Type: disposable	Duplicate ID:	Sample Time:
Other: [ ] Desc.:	Equip. blank ID:	Sample Time:

CDM MONITORING WELL PURGE AND SAMPLING FORM

Well No.: AMW1 | Site: Seal Beach | Date: 10/2/07

Time	Gallons	Temp. (°C/°F)	pH	Conductivity (µmhos/cm)	Turbidity (NTUs)	DO (mg/L)	ORP (mV)	DTW (ft TOC)	Comments
1350	≈0.6gpm	23.30	7.24	17477	261	9.19	54.9	32.27	20 mins
1400	—	well	went	Dry	—	—	—	—	—
1425	≈0.6gpm	23.34	7.17	16312	101	8.83	70.6	31.89	5 mins
1535	≈0.6gpm	23.14	7.08	15291	65	9.17	86.5	30.10	5 mins
1545	≈0.6gpm	23.89	7.16	16772	410	8.29	48.7	32.63	15 mins
1555	≈0.6gpm	23.68	7.11	16892	207	8.01	56.3	32.89	25 mins
1600	≈1.1gpm	Well stop	pumping	for	today	—	—	—	—
10/3 0740	—	Begin	to Pump	well	—	—	—	STWL 19.04	—
0745	≈0.8gpm	22.86	7.09	15788	638	6.00	228.4	24.21	5 mins
0755	≈0.7gpm	22.68	7.13	16224	830	6.01	208.9	26.27	15 mins
0805	≈0.7gpm	23.06	7.19	16884	497	5.81	155.2	27.39	25 mins
0815	≈0.6gpm	23.23	7.12	16258	788	6.15	172.4	28.86	35 mins
0830	≈0.5gpm	23.45	7.19	16650	137	6.76	113.2	30.00	50 mins
0845	≈0.5gpm	23.17	7.26	17687	87	6.91	96.1	32.85	65 mins
0855	—	well	went	Dry	—	—	—	—	—
0925	—	Resume	Pumping	—	—	—	—	STWL 29.68	—
0930	≈0.5gpm	22.85	7.12	14915	189	7.48	205.2	31.72	5 mins
0940	≈0.5gpm	23.27	7.24	16584	332	7.30	165.4	33.24	15 mins
0950	≈0.5gpm	23.87	7.20	15855	512	6.49	167.7	33.89	25 mins
0955	—	well	went	Dry	—	—	—	—	—
1025	—	Resume	Pumping	—	—	—	—	STWL 29.11	—
1030	≈0.5gpm	23.28	7.09	15056	102	7.83	177.5	31.09	~~5~~ 5 mins
1040	≈0.5gpm	24.05	7.14	15913	53	7.35	217.6	32.74	15 mins
1055	≈0.5gpm	24.21	7.15	15881	259	7.29	253.0	33.48	30 mins
1105	≈0.5gpm	24.68	7.16	16069	~~395~~	7.63	93.5	33.91	40 mins
1125	≈0.5gpm	24.87	7.13	15814	48	9.81	142.6	33.93	60 mins
1130	—	well	went	Dry	—	—	—	—	—
1200	—	Resume	Pumping	—	—	—	—	STWL 28.26	—
1210	≈0.5gpm	23.90	7.03	14610	109	10.89	123.1	29.78	10 mins
1220	≈0.5gpm	23.98	7.05	15407	111	11.10	153.2	31.13	20 mins
1240	≈0.5gpm	24.61	7.08	15731	17	12.13	~~227~~ 227	32.06	40 mins
1255	≈0.5gpm	24.92	7.09	15532	39	11.91	142.1	31.99	55 mins
1305	—	well	went	Dry	—	—	—	—	65 mins
1330	—	Resume	Pumping	—	—	—	—	STWL 29.37	—
1340	≈0.5gpm	24.47	7.05	15017	127	14.23	120.6	30.19	10 mins
1350	≈0.5gpm	24.32	7.04	14881	91	13.82	33.4	30.47	20 mins
1400	≈0.6gpm	24.29	7.08	14999	206	13.36	129.8	32.81	30 mins
1410	Adjusted slightly up	—	well	went	Dry	—	—	—	—
1430	—	Resume	Pumping	—	—	—	—	STWL 29.86	—
1435	≈0.5gpm	23.69	7.06	14877	76	15.40	128.7	30.73	5 mins
1450	≈0.5gpm	24.20	7.07	15620	41	16.16	404.6	31.97	20 mins

Well No.: AMW 1			Site: Seal Beach				Date: 10/3/07		
Time	Gallons	Temp. (°C)/°F)	pH	Conductivity (µmhos/cm)	Turbidity (NTUs)	DO (mg/L)	ORP (mV)	DTW (ft TOC)	Comments
1510	≈0.5gpm	24.28	7.13	15955	786	15.98	398.2	33.86	40 mins
1520	≈0.5gpm	24.52	7.12	15831	453	15.41	372.9	33.88	50 mins
1535	≈0.4gpm	24.66	7.10	15675	81	14.85	346.2	33.92	65 mins
1545	—	well	went	Dry	—	—	—	STWL	75 mins
1550	—	Resume	Pumping	well	—	—	—	30.01	
1555	≈0.4gpm	23.98	7.08	15526	199	17.17	485.2	33.27	5 mins
1600	120gal.	Stop	pumping	For	Today	—	—	—	10 mins
10/4 0725	—	Begin	to	Pump	well	—	—	STWL	—
0730	≈0.5gpm	22.28	7.69	15921	152	5.97	508.7	22.51	5 mins
0740	≈0.5gpm	23.02	7.07	15331	593	6.01	513.0	25.44	15 mins
0750	≈0.5gpm	23.05	7.11	16093	359	5.95	443.9	27.64	25 mins
0805	≈0.5gpm	23.10	7.07	15528	91	8.16	310.9	29.38	40 mins
0820	≈0.5gpm	23.46	7.13	15902	35	10.40	157.7	31.02	55 mins
0840	≈0.5gpm	23.35	7.15	15430	90	12.64	159.8	33.86	75 mins
0850	—	well	went	Dry	—	—	—	—	85 mins
0920	—	Resume	Pumping	well	—	—	—	STWL 28.96	—
0925	≈0.5gpm	22.78	7.12	14811	83	8.84	80.4	29.67	5 mins
0940	≈0.5gpm	23.89	7.09	14844	32	13.78	106.5	30.63	20 mins
0955	≈0.5gpm	23.18	7.10	15533	18	13.96	495.2	32.31	35 mins
1005	≈0.5gpm	23.98	7.13	15657	409	12.49	46.5	33.75	45 mins
1010	—	well	went	Dry	—	—	—	—	—
1030	—	Resume	Pumping	well	—	—	—	STWL 29.96	—
1035	≈0.5gpm	24.08	7.07	14682	26	15.54	49.2	30.25	5 mins
1045	≈0.5gpm	24.11	7.05	14453	13	15.78	118.6	30.99	15 mins
1050	≈0.5gpm	24.30	7.04	14523	8	16.10	132.6	31.07	20 mins
1100	≈0.5gpm	24.36	7.05	14502	4.9	16.14	136.2	31.26	30 mins
1100	70gal.	—	Stop	Pumping	Go	to	next	well	—

Well No.: AMW2	Site: Seal Beach	Date: 10/4/07
Client:	Project Number:	
Well Casing Diameter (inches): 4"	Well Casing Material: (PVC) SS Other:	
Well Headspace: PID (ppm): 0.0 ppm	FID (ppm): N/A	
Samplers: Chad Martin with CDM	with Blaine Tech	

Total Depth of Well (feet): 35 — 2" - 0.16
Depth to Water (feet): 19.32 TOC (X) 4" - 0.65 Gal/ft. = 10.19 (X) 3 = _____ ← Minimum purge volume (gallons)
Water Column Height (feet): 15.68 — 6" - 1.47
Well Reference Point: **TOC** — __" - ____

PURGE METHOD: Submersible pump [X] Bladder pump [ ] Disposable bailer [ ]

Pump Make/Model: 2" Grundfos Rediflo	Depth of pump intake (feet):
Purge equipment decontaminated? Y [X] N [ ]	Container type:
Purge/decon water containerized? Y [X] N [ ]	Volume: Bailed = 65 gallons Pumped = 545 gallons

Start Time: _____ Flow Rate: _____

Time	Gallons	Temp. (°C)/°F)	pH	Conductivity (µmhos/cm)	Turbidity (NTUs)	DO (mg/L)	ORP (mV)	DTW (ft TOC)	Comments
1130	—	Begin to surge & Bail							
1205	4	23.82	7.36	19221	>1000	8.26	224.1	—	surge & Bail
1210	20	well went dry							
1230	40	23.24	7.38	19384	>1000	18.59	234.6	—	surge & Bail
1235	43	well went dry							
1310	48	22.59	7.24	19503	>1000	13.10	326.2	—	surge & Bail
1320	65	Finished w/ surge & Bail							
1345	—	Begin to Pump well							
1350	≈0.7gpm	22.59	7.10	20190	>1000	2.78	-5.2	22.18	Pumping
1400	≈0.6gpm	22.82	7.10	19006	>1000	5.75	70.6	23.23	15mins
1415	≈0.6gpm	22.96	7.05	18702	>1000	7.74	101.1	23.82	30mins
1430	≈0.6gpm	22.99	7.03	18727	492	4.21	88.9	24.10	45mins
1445	≈0.6gpm	22.96	7.06	19098	882	6.35	77.4	24.27	60mins
1500	≈0.6gpm	23.09	7.05	18677	791	7.01	24.1	24.32	75mins
1515	≈0.8gpm	23.01	7.05	19256	554	7.06	98.1	27.49	90mins

Chemets DO (mg/L): _____

	Method	Container Type/Volume	Preservative
Sample Analyses: →			
Sample Collection Method: ↘			

Pump: [ ] Flow Rate:	Sample ID:	Sample Time:
Bailer: [ ] Type: disposable	Duplicate ID:	Sample Time:
Other: [ ] Desc.:	Equip. blank ID:	Sample Time:

CDM MONITORING WELL PURGE AND SAMPLING FORM

Well No.: AMW2 | Site: Seal Beach | Date: 10/5/07

Time	Gallons	Temp. (°C/°F)	pH	Conductivity (µmhos/cm)	Turbidity (NTUs)	DO (mg/L)	ORP (mV)	DTW (ft TOC)	Comments
1530	≈0.8gpm	23.02	7.07	19457	253	4.10	100.6	28.11	105 mins
1545	≈0.8gpm	22.97	7.06	19240	284	3.75	69.1	28.19	120mins
1600	≈0.8gpm	22.88	7.09	19910	183	4.11	123.8	30.21	135mins
1600	140gal	Stop Pumping for Today							
10/5 0800	—	Begin to Pump well						STWL 19.45	
0805	≈0.7gpm	22.53	7.12	19285	174	5.54	481.7	23.65	5 mins
0815	≈0.7gpm	22.45	7.08	19310	43	4.42	407.8	25.02	15 mins
0830	≈0.8gpm	22.88	7.06	19053	389	3.46	341.2	25.98	30 mins
0845	≈0.9gpm	22.64	7.06	19146	65	3.60	139.3	26.78	45 mins
0900	≈1gpm	22.78	7.07	19168	111	8.66	133.1	26.88	60 mins
0915	≈1gpm	22.65	7.10	19777	260	3.04	74.9	30.04	75min
0930	≈1.2gpm	23.05	7.09	19560	182	3.12	79.8	31.17	90 mins
1000	≈1.2gpm	22.75	7.09	19388	14	3.46	122.0	31.42	120mins
1005	155gal	Stop pumping Let well Recover							
1030	—	Resume Pumping well						STWL 21.02	
1035	≈1.2gpm	23.97	7.08	19105	74	3.71	116.1	23.98	5 mins
1040	≈1.2gpm	22.67	7.05	18685	108	4.80	125.1	25.38	10mins
1050	≈1.2gpm	22.76	7.04	18849	110	3.03	113.9	26.84	20mins
1105	≈1.2gpm	22.80	7.06	19204	23	4.85	124.6	27.64	35mins
1120	≈1.2gpm	22.76	7.06	19138	6	3.17	119.1	27.69	50mins
1130	≈1.2gpm	22.89	7.06	19111	38	4.01	108.7	27.82	60mins
1140	240gal	Stop pumping for Today							
10/8 0720	—	Begin to pump well						STWL 19.52'	
0725	≈1.2gpm	22.50	7.14	20,398	39	4.80	475.2	23.34	5mins
0735	≈1.2gpm	22.72	7.10	19963	11	3.95	469.7	26.07	15mins
0750	≈1.2gpm	22.68	7.08	19719	13	3.94	414.0	27.61	30mins
0805	≈1.2gpm	22.72	7.07	19407	5.3	3.71	385.0	28.29	45mins
0820	≈1.2gpm	22.79	7.07	19177	2.6	3.29	350.9	28.57	60mins
0820	—	Stop Pumping Let well recover							
0840	—	Resume Pumping well						STWL 20.96	
0845	≈1.2gpm	22.78	7.05	18926	16.1	3.37	353.8	24.14	5mins
0855	≈1.2gpm	22.79	7.04	18768	13.2	3.80	339.6	26.74	15mins
0910	≈1.2gpm	22.81	7.05	19214	8.1	2.79	280.7	27.78	30mins
0925	≈1.2gpm	22.81	7.06	19240	5.32	3.01	244.9	28.49	45mins
0940	≈1.2gpm	22.82	7.06	19245	2.81	3.08	239.6	28.60	60mins
0940	165gall.	Finished Pumping well Developed							

Well No.: AMW 3 Z 1	Site: Seal Beach	Date: 10/9/07
Client:	Project Number:	
Well Casing Diameter (inches):	Well Casing Material: PVC SS (Other) Poly	
Well Headspace: PID (ppm): 0.0	FID (ppm): N/A	
Samplers: Chad Marvin with CDM	with Blaine Tech	

Total Depth of Well (feet): 35 — 2" - 0.16
Depth to Water (feet): 19.87 (X) 4" - 0.65 Gal/ft. = _____ (X) 3 = _____
Water Column Height (feet): _____ — 6" - 1.47 — Minimum purge volume (gallons)
Well Reference Point: TOC — " - _____

PURGE METHOD: Submersible pump ☐ Bladder pump ☐ Disposable bailer ☐

Pump Make/Model: 2" Grundfos Rediflo	Depth of pump intake (feet):
Purge equipment decontaminated? Y ☒ N ☐	Container type:
Purge/decon water containerized? Y ☒ N ☐	Volume: Peristaltic Pumping = 11 gallons

Start Time: _____ Flow Rate: _____

Time	Gallons	Temp. (°C/°F)	pH	Conductivity (µmhos/cm)	Turbidity (NTUs)	DO (mg/L)	ORP (mV)	DTW (ft TOC)	Comments
1445	———	Begin to Pump						stwl 19.87	———
1450	≈ 1 gal	26.57	7.24	20284	>1000	6.69	131.7	can't measure water fit while	Pumping
1455	≈ 1.3 gal	25.61	7.16	20781	388	4.82	50.7		"
1500	≈	24.61	7.18	20502	421	5.01	29.2		"
1505	≈	24.17	7.16	20501	509	3.18	21.0	Pumping	"
1510		24.33	7.16	21014	269	2.71	-3.9	N/A	"
1515		24.09	7.18	21320	17.3	3.74	3.8	"	"
1520	≈ 2.5 gal	23.88	7.15	20622	196	3.95	-34.9	"	"
1535		23.56	7.21	21539	51.8	5.14	55.1	"	"
1545	≈ 5 gal	23.37	7.16	21576	80	4.16	50.3	"	
1555		23.28	7.20	21755	384	4.10	-4.2		
1600	≈ 6 gal	stop Pumping for Today				———			———
10/10 0725	———	Begin to Pump we 11				———		stwl 19.98	———
0730		21.03	7.25	21946	64	8.21	25.3	—	Pumping
0740		20.49	7.24	22435	139	8.46	-7.2	—	

Chemets DO (mg/L): _____

	Method	Container Type/Volume	Preservative
Sample Analyses: →			
Sample Collection Method: ↘			

Pump: ☐ Flow Rate:	Sample ID:	Sample Time:
Bailer: ☐ Type: disposable	Duplicate ID:	Sample Time:
Other: ☐ Desc.:	Equip. blank ID:	Sample Time:

CDM — MONITORING WELL PURGE AND SAMPLING FORM

Well No.: AMW3 Z1 | Site: Seal Beach | Date: 10/9/07

Time	Gallons	Temp. (°C/°F)	pH	Conductivity (µmhos/cm)	Turbidity (NTUs)	DO (mg/L)	ORP (mV)	DTW (ft TOC)	Comments
0750	≈2 gal	22.08	7.20	21891	47	4.90	-7.2	—	Pumping
0800	≈2.5 gal	22.04	7.24	22006	66	4.62	-7.3	—	"
0810		21.33	7.22	22179	18	3.55	-15.9	—	"
0820		21.09	7.21	22481	4.92	3.86	-18.0	—	
0825	≈5 gal	21.16	7.22	22501	0.91	3.91	-19.2	—	
0825	—	Finished Pumping		Zone #1 Developed				—	

Well No.: AMW3 Z2	Site: Seal Beach	Date: 10/10/07
Client:	Project Number:	
Well Casing Diameter (inches):	Well Casing Material: PVC SS (Other: Poly)	
Well Headspace: PID (ppm): 0.0		
Samplers: Chad Martin with CDM	~~with Blaine Tech~~	

Total Depth of Well (feet): 35 — 2" - 0.16
Depth to Water (feet): 0.0 — (X) 4" - 0.65 Gal/ft. = _____ (X) 3 = _____
Water Column Height (feet): _____ — 6" - 1.47 — Minimum purge volume (gallons)
Well Reference Point: _____ — "-____

PURGE METHOD: Submersible pump ☐ Bladder pump ☐ Disposable bailer ☐	
Pump Make/Model: 2" Grundfos Rediflo	Depth of pump intake (feet):
Purge equipment decontaminated? Y ☒ N ☐	Container type:
Purge/decon water containerized? Y ☒ N ☐	Volume: ~~_____~~

Start Time: _____ Flow Rate: _____

Time	Gallons	Temp. (°C/°F)	pH	Conductivity (µmhos/cm)	Turbidity (NTUs)	DO (mg/L)	ORP (mV)	DTW (ft TOC)	Comments
NO WATER ZONE DRY									

Chemets DO (mg/L): _____

Sample Analyses: →	Analyzed ?	EPA Method	Container Type/Volume	Preservative
Sample Collection Method: ↙				

Pump: ☐ Flow Rate:	Sample ID:	Sample Time:
Bailer: ☐ Type: disposable	Duplicate ID:	Sample Time:
Other: ☐ Desc.:	Equip. blank ID:	Sample Time:

CDM

MONITORING WELL PURGE AND SAMPLING FORM

Well No.: AMW3 Z3	Site: Seal Beach	Date: 10/10/07
Client:	Project Number:	
Well Casing Diameter (inches):	Well Casing Material: PVC SS (Other) Poly	
Well Headspace: PID (ppm): 0.0		
Samplers: Chad Marvin with CDM	~~with Blaine Tech~~	

Total Depth of Well (feet): 35 — 2" - 0.16

Depth to Water (feet): 0 — (X) 4" - 0.65 Gal/ft. = _____ (X) 3 = _____

Water Column Height (feet): _____ — 6" - 1.47 — Minimum purge volume (gallons)

Well Reference Point: _____ — " - _____

PURGE METHOD: Submersible pump ☐ Bladder pump ☐ Disposable bailer ☐

Pump Make/Model: 2" Grundfos Rediflo — Depth of pump intake (feet):

Purge equipment decontaminated? Y ☒ N ☐ — Container type:

Purge/decon water containerized? Y ☒ N ☐ — Volume: ~~Volume:~~

Start Time: _____ Flow Rate: _____

Time	Gallons	Temp. (°C/°F)	pH	Conductivity (µmhos/cm)	Turbidity (NTUs)	DO (mg/L)	ORP (mV)	DTW (ft TOC)	Comments
No Water Zone Dry									

Chemets DO (mg/L): _____

Sample Analyses: →	Analyzed ?	EPA Method	Container Type/Volume	Preservative
Sample Collection Method: ↙				

Pump: ☐ Flow Rate:	Sample ID:	Sample Time:
Bailer: ☐ Type: disposable	Duplicate ID:	Sample Time:
Other: ☐ Desc.:	Equip. blank ID:	Sample Time:

CDM

MONITORING WELL PURGE AND SAMPLING FORM

Well No.: AMW3 Z4	Site: Seal Beach	Date: 10/10/07
Client:	Project Number:	
Well Casing Diameter (inches): CMT well	Well Casing Material: PVC SS (Other:) Poly	
Well Headspace: PID (ppm): 0.0	FID (ppm): N/A	
Samplers: Chad Marvin with CDM	~~with Blaine Tech~~	

Total Depth of Well (feet): 35 — 2" - 0.16

Depth to Water (feet): 17.38' (X) 4" - 0.65 Gal/ft. = _____ (X) 3 = _____

Water Column Height (feet): _____ — 6" - 1.47 — Minimum purge volume (gallons)

Well Reference Point: **TOC** — " - _____

PURGE METHOD: Submersible pump ☐ Bladder pump ☐ Disposable bailer ☐

Pump Make/Model: 2" Grundfos Rediflo	Depth of pump intake (feet):
Purge equipment decontaminated? Y ☒ N ☐	Container type:
Purge/decon water containerized? Y ☒ N ☐	Volume: Peristaltic Pump = ¼ gallon

Start Time: _____ Flow Rate: _____

Time	Gallons	Temp. (°C/°F)	pH	Conductivity (µmhos/cm)	Turbidity (NTUs)	DO (mg/L)	ORP (mV)	DTW (ft TOC)	Comments
0925	—	Begin to Pump Z			one #	4	—	SWL 17.38'	—
0930		23.40	7.74	14406	>1000	6.21	65.5	B.TOP.	Pumping
0931	≈¼ gal	well	went	Dry	—	—	—	—	—

Chemets DO (mg/L): _____

	Method	Container Type/Volume	Preservative
Sample Analyses: →			
Sample Collection Method: ↘			

Pump: ☐ Flow Rate:	Sample ID:	Sample Time:
Bailer: ☐ Type: disposable	Duplicate ID:	Sample Time:
Other: ☐ Desc.:	Equip. blank ID:	Sample Time:

CDM

MONITORING WELL PURGE AND SAMPLING FORM

Well No.: AMW4Z1	Site: Seal Beach	Date: 10/10/07
Client:	Project Number:	
Well Casing Diameter (inches):	Well Casing Material: PVC SS (Other) Poly	
Well Headspace: PID (ppm): 0.0		
Samplers: Chad Marvin with CDM ~~with Blaine Tech~~		

Total Depth of Well (feet): 35 — 2" - 0.16

Depth to Water (feet): 15.70 (X) 4" - 0.65 Gal/ft. = _____ (X) 3 = _____

Water Column Height (feet): _____ — 6" - 1.47 — Minimum purge volume (gallons)

Well Reference Point: _____ — "-____

PURGE METHOD: Submersible pump ☐ Bladder pump ☐ Disposable ba ☐

Pump Make/Model: 2" Grundfos Rediflo	Depth of pump intake (feet):
Purge equipment decontaminated? Y ☒ N ☐	Container type:
Purge/decon water containerized? Y ☒ N ☐	Volume: Peristaltic Pump = 23.5 gallons

Start Time: _____ Flow Rate: _____

Time	Gallons	Temp. (°C/°F)	pH	Conductivity (µmhos/cm)	Turbidity (NTUs)	DO (mg/L)	ORP (mV)	DTW (ft TOC)	Comments
0955		Begin to Pump Well						STVL 15.70	
1000		22.61	7.36	21304	>1000	2.51	36.8		Pumping
1005	≈ 1 gal	22.35	7.31	21054	484	1.77	7.1		"
1010	≈ 1.5 gal	22.49	7.32	20967	780	2.08	-13.0		"
1020	≈ 2 gal	22.64	7.27	20809	478	3.90	-4.1		"
1030		22.48	7.30	21045	638	4.13	9.0		"
1045	≈ 5 gal	23.08	7.26	21129	409	4.06	24.2		"
1100		23.86	7.20	20966	218	2.79	50.8		"
1115	≈ 7.5 gal	23.68	7.20	21234	113	2.70	55.6		"
1130	≈ 9 gal	23.45	7.21	21086	201	2.72	60.0		"
1145	≈ 10 gal	23.46	7.20	21108	84	2.57	57.2		"
1155		Stop Pumping Well ≈ 1							"
1215		Resume Pumping							
1225	≈ 12 gal	22.90	7.21	21128	56	3.20	81.2		Pumping
1245	≈ 14 gal	23.03	7.19	21116	148	3.26	78.0		"

Chemets DO (mg/L): _____

Sample Analyses: →	Analyzed ?	EPA Method	Container Type/Volume	Preservative
Sample Collection Method: ↙				

Pump: ☐ Flow Rate:	Sample ID:	Sample Time:
Bailer: ☐ Type: disposable	Duplicate ID:	Sample Time:
Other: ☐ Desc.:	Equip. blank ID:	Sample Time:

CDM

MONITORING WELL PURGE AND SAMPLING FORM

Well No.: AMW4 Z1 | Site: Seal Beach | Date: 10/10/07

Time	Gallons	Temp. (°C/°F)	pH	Conductivity (µmhos/cm)	Turbidity (NTUs)	DO (mg/L)	ORP (mV)	DTW (ft TOC)	Comments
1300	≈15.5 gal	23.04	7.18	21207	167	2.98	46.2	—	Pumping
1315	≈17.5 gal	22.94	7.20	21128	105	2.90	50.2	—	"
1330	≈18.5 gal	22.87	7.21	21110	44	3.04	46.8	—	"
1345	≈20 gal	23.05	7.20	21142	32.1	3.20	55.5	—	"
1400		23.04	7.23	21179	15.6	3.62	55.0	—	"
1415	≈22.5 gal	22.80	7.24	21138	8.1	3.78	57.2	—	"
1425		22.76	7.24	21137	2.13	3.81	49.8	—	"
1430	≈23.5	2275	7.23	21146	2.81	3.69	38.7	—	"
1430	≈23.5 gal	—	Stop	Pumping	Z1	Fully	Developed	—	—

Well No.: AMW 4 Z2	Site: Seal Beach	Date: 10/10/07
Client:	Project Number:	
Well Casing Diameter (inches):	Well Casing Material: PVC SS (Other) Poly	
Well Headspace: PID (ppm): 0.0	FID (ppm): N/A	
Samplers: Chad Marvin with CDM	~~with Blaine Tech~~	

Total Depth of Well (feet): _____ 2" - 0.16
Depth to Water (feet): 19.29 (X) 4" - 0.65 Gal/ft. = _____ (X) 3 = _____ ← Minimum purge volume (gallons)
Water Column Height (feet): _____ 6" - 1.47
Well Reference Point: **TOC** __" - ____

PURGE METHOD: Submersible pump ☐ Bladder pump ☐ Disposable bailer ☐

Pump Make/Model: 2" Grundfos Rediflo	Depth of pump intake (feet):
Purge equipment decontaminated? Y ☒ N ☐	Container type:
Purge/decon water containerized? Y ☒ N ☐	Volume: Peristaltic Pump = 17.5 gallons

Start Time: _____ Flow Rate: _____

Time	Gallons	Temp. (°C/°F)	pH	Conductivity (µmhos/cm)	Turbidity (NTUs)	DO (mg/L)	ORP (mV)	DTW (ft TOC)	Comments
1440	—	Begin	to	Pump	Z2	—	—	STUL 19.29 BTOP	—
1445		23.27	7.17	20648	>1000	4.02	79.4	—	Pumping
1500	≈2.2 gal	23.22	7.16	21025	331	4.00	70.1	—	"
1515		23.16	7.15	21008	140	3.75	87.9	—	"
1530	≈5 gal	22.91	7.14	21040	149	3.68	98.2	—	"
1545		23.09	7.20	20476	257	3.94	106.5	—	"
1600		22.88	7.16	21062	108	3.96	112.7	—	"
1605	≈7.5 gal	—	stop	Pumping	for	Today	—	—	—
10/11 0715	—	—	Resume	Pumping	—	—	—	—	—
0720		21.31	7.23	20994	172	4.16	155.0	—	Pumping
0730		21.88	7.19	20702	57.2	3.92	127.9	—	"
0745	≈2.5 gal	21.86	7.17	20826	44.3	3.57	101.0	—	"
0800	≈4 gal	22.17	7.18	20944	31.2	3.05	97.9	—	"
0815	≈5.5 gal	22.42	7.18	19890	17.4	3.16	98.2	—	"
0830		22.33	7.19	20897	10.1	3.29	97.0	—	"

Chemets DO (mg/L): _____

	Method	Container Type/Volume	Preservative
Sample Analyses: →			
Sample Collection Method: ↘			

Pump: ☐ Flow Rate:	Sample ID:	Sample Time:
Bailer: ☐ Type: disposable	Duplicate ID:	Sample Time:
Other: ☐ Desc.:	Equip. blank ID:	Sample Time:

CDM MONITORING WELL PURGE AND SAMPLING FORM

Well No.: AMW4Z2 | Site: Seal Beach | Date: 10/11/07

Time	Gallons	Temp. (°C/°F)	pH	Conductivity (µmhos/cm)	Turbidity (NTUs)	DO (mg/L)	ORP (mV)	DTW (ft TOC)	Comments
0845	≈ 9gal	22.55	7.17	20964	5.02	3.19	107.2	—	Pumping
0900	≈ 10gal	22.47	7.17	20896	1.24	3.26	105.9	—	"
0900	—	stop Pump Zone 2 Developed							
Total = 17.5gallons									

Well No.: AMW4 Z3	Site: Seal Beach	Date: 10/11/07
Client:	Project Number:	
Well Casing Diameter (inches):	Well Casing Material: PVC SS (Other) Poly	
Well Headspace: PID (ppm): 0.0		
Samplers: Chad Marvin with CDM	~~with Blaine Tech~~	

Total Depth of Well (feet): 35 — 2" - 0.16
Depth to Water (feet): 19.27 (X) 4" - 0.65 Gal/ft. = _____ (X) 3 = _____
Water Column Height (feet): _____ — 6" - 1.47 — Minimum purge volume (gallons)
Well Reference Point: _____ " - _____

PURGE METHOD: Submersible pump ☐ Bladder pump ☐ Disposable ba ☐

Pump Make/Model: 2" Grundfos Rediflo	Depth of pump intake (feet):
Purge equipment decontaminated? Y ☒ N ☐	Container type:
Purge/decon water containerized? Y ☒ N ☐	Volume: Peristaltic Pump = 9 gallons

Start Time: _____ Flow Rate: _____

Time	Gallons	Temp. (C/F)	pH	Conductivity (µmhos/cm)	Turbidity (NTUs)	DO (mg/L)	ORP (mV)	DTW (ft TOC)	Comments
0915	———	Begin	to Pump	Well				STWL 19.27'	———
0920		23.14	7.58	22086	>1000	5.50	28.2	—	Pumping
0930	≈1 gal	23.41	7.44	21991	302	4.88	28.4	—	"
0945		23.96	7.44	22253	46	4.96	37.0	—	"
1000	≈2.5 gal	23.58	7.45	22248	27.1	5.03	36.1	—	"
1015		23.14	7.38	22050	47.6	4.36	36.7	—	"
1030		23.29	7.39	21890	32.8	4.17	21.1	—	"
1045	≈5 gal	23.20	7.38	21810	19.3	4.24	32.6	—	"
1100		22.89	7.35	21691	13.4	3.18	22.0	—	"
1115		22.71	7.36	20908	22.9	4.01	26.8	—	"
1130	≈7.5 gal	22.95	7.33	21002	6.89	3.26	27.8	-	"
1145		23.10	7.34	21300	5.01	3.34	26.0	-	"
1200	≈9 gal	23.15	7.33	21096	1.48	3.39	29.4	—	"
1200	———	stop	pumping	Zone 3	fully	Developed		———	———

Chemets DO (mg/L): _____

Sample Analyses: →	Analyzed ?	EPA Method	Container Type/Volume	Preservative
Sample Collection Method: ↙				

Pump: ☐ Flow Rate:	Sample ID:	Sample Time:
Bailer: ☐ Type: disposable	Duplicate ID:	Sample Time:
Other: ☐ Desc.:	Equip. blank ID:	Sample Time:

CDM — MONITORING WELL PURGE AND SAMPLING FORM

Well No.: AMW 4 Z4	Site: Seal Beach	Date: 10/11/07
Client:	Project Number:	
Well Casing Diameter (inches):	Well Casing Material: PVC SS (Other: Poly)	
Well Headspace: PID (ppm): 0.0		
Samplers: Chad Marvin with CDM	~~with Blaine Tech~~	

Total Depth of Well (feet): 35 — 2" - 0.16

Depth to Water (feet): 18.10 — (X) 4" - 0.65 Gal/ft. = _____ (X) 3 = _____

Water Column Height (feet): _____ — 6" - 1.47 — Minimum purge volume (gallons)

Well Reference Point: _____ — __" - ____

PURGE METHOD: Submersible pump ☐ Bladder pump ☐ Disposable ba☐

Pump Make/Model: 2" Grundfos Rediflo	Depth of pump intake (feet):
Purge equipment decontaminated? Y ☒ N ☐	Container type:
Purge/decon water containerized? Y ☒ N ☐	Volume: Peristaltic Pump = 6 oz

Start Time: _____ Flow Rate: _____

Time	Gallons	Temp. (°C/°F)	pH	Conductivity (µmhos/cm)	Turbidity (NTUs)	DO (mg/L)	ORP (mV)	DTW (ft TOC)	Comments
1215	—	Begin to Pump Zone 4						Stwl 18.10'	
1218	6 oz	Well went Dry							

Chemets DO (mg/L): _____

Sample Analyses: →	Analyzed ?	EPA Method	Container Type/Volume	Preservative
Sample Collection Method: ↙				

Pump: ☐ Flow Rate:	Sample ID:	Sample Time:
Bailer: ☐ Type: disposable	Duplicate ID:	Sample Time:
Other: ☐ Desc.:	Equip. blank ID:	Sample Time:

CDM

MONITORING WELL PURGE AND SAMPLING FORM

Well No.: AMW5 Z1	Site: Seal Beach	Date: 10/11/07
Client:	Project Number:	
Well Casing Diameter (inches):	Well Casing Material: PVC SS Other: Poly	
Well Headspace: PID (ppm): 0.0		
Samplers: Chad Marvin with CDM		~~with Blaine~~

Total Depth of Well (feet): 35 2" - 0.16

Depth to Water (feet): 18.25' (X) 4" - 0.65 Gal/ft. = _____ (X) 3 = _____ Minimu

Water Column Height (feet): _____ 6" - 1.47

Well Reference Point: __" - ____

PURGE METHOD: Submersible pump ☐ Bladder pump ☐ Disposable bailer ☐

Pump Make/Model: 2" Grundfos Rediflo	Depth of pump intake (feet):
Purge equipment decontaminated? Y ☐ N ☐	Container type:
Purge/decon water containerized? Y ☐ N ☐	Volume: Peristaltic Pump = 53 gallons

Start Time: _____ Flow Rate: _____

Time	Gallons	Temp. (°C/°F)	pH	Conductivity (µmhos/cm)	Turbidity (NTUs)	DO (mg/L)	ORP (mV)	DTW (ft TOC)
1235	—	Begin to Pump Zone 1						STWL 18.25'
1240		24.06	7.05	13278	>1000	4.32	-63.3	— Pumping
1250		23.24	7.18	11748	989	3.21	-51.9	—
1300	≈2.5gal	22.89	7.16	11025	>1000	4.06	-53.6	—
1315		22.82	7.23	10158	731	2.90	-50.1	—
1330	≈5gal	22.80	7.23	9793	616	2.94	-43.3	—
1345	≈6.5gal	23.18	7.26	9857	363	3.08	-44.3	—
1400	≈9.5gal	23.03	7.26	9597	305	3.30	-43.4	
1415	≈10.8gal	22.95	7.27	10186	192	3.80	-40.9	—
1430	≈12.5gal	22.71	7.25	9487	177	3.46	-40.7	
1445	≈15gal	22.59	7.25	9671	70.5	3.40	-40.6	—
1500	≈17gal	22.50	7.28	8603	55.0	3.75	-42.1	—
1515	≈18.5gal	22.79	7.28	9136	36.2	3.72	-42.1	—
1530	≈20gal	22.53	7.29	9382	193	3.81	-37.6	—
1545	^	22.49	7.28	9100	172	3.94	-42.2	

Chemets DO (mg/L): _____

	Analyzed ?	EPA Method	Container Type/Volume
Sample Analyses: →			
Sample Collection Method: ↙			

Pump: ☐ Flow Rate:	Sample ID:	Sample Time:
Bailer: ☐ Type: disposable	Duplicate ID:	Sample Time:
Other: ☐ Desc.:	Equip. blank ID:	Sample Time:

CDM MONITORING WELL PURGE AND SAMPLING FORM

Well No.: AMW5 Z1 | Site: Seal Beach | Date: 10/11/07

Time	Gallons	Temp. (°C/°F)	pH	Conductivity (µmhos/cm)	Turbidity (NTUs)	DO (mg/L)	ORP (mV)	DTW (ft TOC)	Comments
1600		22.54	7.30	9013	84.7	4.58	-39.3	—	
1610	24 gal	—	Stop pumping for Today						
10/12 0725	—	Begin to Pump Zone 1							
0730		21.81	7.19	10149	369	6.51	-43.3	—	Pumping
0745	≈2.5 gal	21.91	7.27	9739	244	6.60	-58.4	—	"
0800	≈5 gal	22.01	7.30	9197	109	5.52	-48.0	—	"
0815		21.87	7.28	9154	134	5.12	-42.8	—	"
0830	≈9 gal	22.07	7.26	9074	98	4.01	-42.7	—	"
0845	≈10 gal	22.07	7.29	9012	226	4.36	-43.8	—	"
0900	≈11.8 gal	22.21	7.29	8958	172	4.61	-41.3	—	"
0915	≈13.5 gal	22.23	7.31	8734	29.2	4.11	-35.6	—	"
0930	≈15.5 gal	22.24	7.29	8963	18.9	4.38	-34.1	—	"
0945	≈17.5 gal	22.19	7.28	8982	61.2	4.19	-36.0	—	"
1000	≈20 gal	21.82	7.30	8911	49.9	5.72	-31.3	—	"
1015	≈22 gal	22.24	7.30	8672	20.8	4.60	-33.2	—	"
1030	≈24 gal	22.43	7.29	8864	16.7	4.70	-33.3	—	"
1045	≈25 gal	22.30	7.31	8794	8.21	5.26	-32.2	—	"
1100		22.92	7.30	8757	4.79	4.96	-32.7	—	"
1115	≈29 gal	22.95	7.30	8769	1.31	4.87	-31.5	—	"
1115	—	—	Stop pumping Zone 1 developed						

Well No.: AMW5 Z2	Site: Seal Beach	Date: 10/12/07
Client:	Project Number:	
Well Casing Diameter (inches):	Well Casing Material: PVC SS Other: Poly	
Well Headspace: PID (ppm): 0.0		
Samplers: Chad Marvin with CDM		~~with Blaine~~

Total Depth of Well (feet): 35 2" - 0.16

Depth to Water (feet): 18.64' (X) 4" - 0.65 Gal/ft. = _____ (X) 3 = _____ ← Minimu

Water Column Height (feet): _____ 6" - 1.47

Well Reference Point: __" - ____

PURGE METHOD: Submersible pump ☐ Bladder pump ☐ Disposable bailer ☐

Pump Make/Model: 2" Grundfos Rediflo	Depth of pump intake (feet):
Purge equipment decontaminated? Y ☒ N ☐	Container type:
Purge/decon water containerized? Y ☒ N ☐	Volume: Peristaltic Pump = 39 gallons

Start Time: _____ Flow Rate: _____

Time	Gallons	Temp. (°C/°F)	pH	Conductivity (µmhos/cm)	Turbidity (NTUs)	DO (mg/L)	ORP (mV)	DTW (ft TOC)	
1130	—	Begin to Pump Zone 2						stwl 18.64'	
1135		23.53	7.34	18900	>1000	6.45	-1.8	—	pumping
1145		23.69	7.17	17571	890	6.82	40.6	—	"
1200		23.70	7.02	17430	980	5.42	56.3	—	"
1215		23.45	6.99	17063	912	5.14	63.0	—	"
1230	≈5 gal	23.31	7.01	17246	899	5.34	58.7	—	"
1245		23.57	7.00	16827	880	4.33	60.0	—	"
1300	≈7.5 gal	23.02	6.97	16754	799	4.42	58.1	—	"
1315	≈9.5 gal	23.34	6.99	16585	845	4.49	59.0	—	"
1330		23.51	6.98	16395	702	5.28	61.0	—	"
1345	≈11.5 gal	23.72	6.99	16344	771	5.69	62.0	—	"
1400		23.41	6.96	16278	810	6.08	63.9	—	"
1415	≈14.5 gal	23.12	6.95	16223	590	5.41	67.8	—	"
1430		23.29	6.96	16431	647	5.50	74.2	—	"
1445	≈17.5	22.99	6.94	16160	605	5.09	72.3	—	"

Chemets DO (mg/L): _____

	Analyzed ?	EPA Method	Container Type/Volume
Sample Analyses: →			
Sample Collection Method: ↙			

Pump: ☐ Flow Rate:	Sample ID:	Sample Time:
Bailer: ☐ Type: disposable	Duplicate ID:	Sample Time:
Other: ☐ Desc.:	Equip. blank ID:	Sample Time:

CDM MONITORING WELL PURGE AND SAMPLING FORM

Well No.: Amw5 Z2 | Site: Seal Beach | Date: 10/12/07

Time	Gallons	Temp. (°C/°F)	pH	Conductivity (µmhos/cm)	Turbidity (NTUs)	DO (mg/L)	ORP (mV)	DTW (ft TOC)	Comments
1500	≈19 gal	23.26	6.94	16032	372	4.80	68.2	—	Pumping
1515		22.79	6.96	16090	499	5.87	70.1	—	"
1530	≈22 gal	22.70	6.97	16157	368	6.02	71.2	—	"
1545		22.54	6.92	15951	339	7.81	73.7	—	"
1600		22.41	6.94	15881	286	7.06	70.1	—	"
1605	≈24 gal	— stop Pumping Z2 for today —							
10/15 0750	—	Begin to Pump Z2 —						STWL 18.38'	
0755		21.31	7.04	16291	181	6.81	129.5	—	Pumping
0815		21.09	7.01	16135	122	6.07	126.2	—	"
0830	≈4 gal	21.46	6.96	16264	53.8	5.60	157.1	—	"
0845		21.80	6.96	16025	30.5	6.09	94.8	—	"
0900	≈7.5 gal	21.88	6.96	15898	16.7	6.18	87.1	—	"
0915	≈10 gal	21.52	6.94	15789	20.0	6.01	81.3	—	"
0930		21.80	6.93	15570	7.3	5.80	77.8	—	"
0945	≈13 gal	21.89	6.92	15618	5.02	4.99	77.9	—	"
1000	≈15 gal	21.88	6.93	15599	3.81	4.98	77.7	—	"
1000	—	stop Pumped Zone 2 Developed —							

Well No.: AMW5 Z3	Site: Seal Beach	Date: 10/15/07
Client:	Project Number:	
Well Casing Diameter (inches):	Well Casing Material: PVC SS (Other) Poly	
Well Headspace: PID (ppm): 0.0		
Samplers: chad Marvin with CDM ~~with Blaine~~		
Total Depth of Well (feet): 35	2" - 0.16	
Depth to Water (feet): 19.73	(X) 4" - 0.65 Gal/ft. = _____	(X) 3 = _____
Water Column Height (feet): _____	6" - 1.47	↖ Minimu
Well Reference Point:	"-	

PURGE METHOD: Submersible pump ☐ Bladder pump ☐ Disposable bailer ☐	
Pump Make/Model: 2" Grundfos Rediflo	Depth of pump intake (feet):
Purge equipment decontaminated? Y ☐ N ☐	Container type:
Purge/decon water containerized? Y ☐ N ☐	Volume: peristaltic Pump = ¼ gallon

Start Time: _____ Flow Rate: _____

Time	Gallons	Temp. (°C/°F)	pH	Conductivity (µmhos/cm)	Turbidity (NTUs)	DO (mg/L)	ORP (mV)	DTW (ft TOC)
1010	—	Begin	to Pump	Zone 5	—	—	—	STWL 19.73'
1015		20.64	7.65	15430	>1000	8.26	76.3	Pumping
1020	¼ gal	Well	went	Dry	—	—	—	—

Chemets DO (mg/L): _____

Sample Analyses: →	Analyzed ?	EPA Method	Container Type/Volume
Sample Collection Method: ↙			

Pump: ☐ Flow Rate:	Sample ID:	Sample Time:
Bailer: ☐ Type: disposable	Duplicate ID:	Sample Time:
Other: ☐ Desc.:	Equip. blank ID:	Sample Time:

CDM

MONITORING WELL PURGE AND SAMPLING FORM

Well No.: AMW5 Z4	Site: Seal Beach	Date: 10/15/07
Client:	Project Number:	
Well Casing Diameter (inches):	Well Casing Material: PVC SS Other Poly	
Well Headspace: PID (ppm): 0.0		
Samplers: Chad Marvin with CDM		~~with Blaine~~

Total Depth of Well (feet): 35 2" - 0.16

Depth to Water (feet): 18.18 (X) 4" - 0.65 Gal/ft. = _____ (X) 3 = _____ ← Minimu

Water Column Height (feet): _____ 6" - 1.47

Well Reference Point: __" - ____

PURGE METHOD: Submersible pump ☐ Bladder pump ☐ Disposable bailer ☐

Pump Make/Model: 2" Grundfos Rediflo	Depth of pump intake (feet):
Purge equipment decontaminated? Y ☒ N ☐	Container type:
Purge/decon water containerized? Y ☒ N ☐	Volume: Peristaltic Pump = 1/3 gallon

Start Time: _____ Flow Rate: _____

Time	Gallons	Temp. (°C/°F)	pH	Conductivity (µmhos/cm)	Turbidity (NTUs)	DO (mg/L)	ORP (mV)	DTW (ft TOC)
1040	—	Begin	to pump	Zone	4	—	—	STWL 18.18'
1045		21.48	7.80	14007	>1000	9.02	83.4	Pumping
1050	1/3 gal	Well	went	Dry				

Chemets DO (mg/L): _____

	Analyzed ?	EPA Method	Container Type/Volume
Sample Analyses: →			
Sample Collection Method: ↙			

Pump: ☐ Flow Rate:	Sample ID:	Sample Time:
Bailer: ☐ Type: disposable	Duplicate ID:	Sample Time:
Other: ☐ Desc.:	Equip. blank ID:	Sample Time:

CDM MONITORING WELL PURGE AND SAMPLING FORM

Well No.: AMW6	Site: Seal Beach	Date: 9/21/07
Client:	Project Number:	
Well Casing Diameter (inches): 4"	Well Casing Material: (PVC) SS Other:	
Well Headspace: PID (ppm): 0.0		
Samplers: Chad Marvin with CDM	~~with Blaine Tech~~	

Total Depth of Well (feet): 35.0 — 2" - 0.16

Depth to Water (feet): 18.86 (X) 4" - 0.65 Gal/ft. = 10.49 (X) 3 = _____

Water Column Height (feet): 16.14 — 6" - 1.47 — Minimum purge volume (gallons)

Well Reference Point: __" - ____

PURGE METHOD: Submersible pump [X] Bladder pump [ ] Disposable ba[ ]

Pump Make/Model: 2" Grundfos Rediflo	Depth of pump intake (feet):
Purge equipment decontaminated? Y [X] N [ ]	Container type: 55 gallon drum
Purge/decon water containerized? Y [X] N [ ]	Volume: Bailed = 74 gallons Pumped = 260 gallons

Start Time: 0730 Flow Rate: _____

Time	Gallons	Temp. (°C) °F)	pH	Conductivity (µmhos/cm)	Turbidity (NTUs)	DO (mg/L)	ORP (mV)	DTW (ft TOC)	Comments
0755	4	21.33	7.36	6571	>1000	4.14	179.2		swab & Bail
0800	9	21.80	7.37	7346	>1000	4.15	166.6		"
0807	17	21.56	7.11	9564	>1000	4.49	161.5		"
0815	29	21.59	7.24	10544	>1000	4.76	160.2		"
~~Begin to Pump well~~								~~16.32~~	

Chemets DO (mg/L): _____

Sample Analyses: →	Analyzed ?	EPA Method	Container Type/Volume	Preservative
Sample Collection Method: ↙				

Pump: [ ] Flow Rate:	Sample ID:	Sample Time:
Bailer: [X] Type: ~~disposable~~ stainless steel	Duplicate ID:	Sample Time:
Other: [ ] Desc.:	Equip. blank ID:	Sample Time:

CDM

MONITORING WELL PURGE AND SAMPLING FORM

Well No.: AMW6	Site: Seal Beach	Date: 10/8/07
Client:	Project Number:	
Well Casing Diameter (inches): 4"	Well Casing Material: (PVC) SS Other:	
Well Headspace: PID (ppm): 0.0	FID (ppm): N/A	
Samplers: Chad Marvin with CDM	~~with Blaine Tech~~	

Total Depth of Well (feet): 35.0 2" - 0.16
Depth to Water (feet): 18.96' (X) 4" - 0.65 Gal/ft. = _____ (X) 3 = _____
Water Column Height (feet): _____ 6" - 1.47 ← Minimum purge volume (gallons)
Well Reference Point: **TOC** "-

PURGE METHOD: Submersible pump [X] Bladder pump [ ] Disposable bailer [ ]

Pump Make/Model: 2" Grundfos Rediflo	Depth of pump intake (feet):
Purge equipment decontaminated? Y [X] N [ ]	Container type:
Purge/decon water containerized? Y [X] N [ ]	Volume:

Start Time: _____ Flow Rate: _____

Time	Gallons	Temp. (°C/°F)	pH	Conductivity (µmhos/cm)	Turbidity (NTUs)	DO (mg/L)	ORP (mV)	DTW (ft TOC)	Comments
1005	———	Begin to	surge	& Bail	well	———		18.96	———
1040	15	23.20	7.18	11327	>1000	5.64	274.5	———	surge & Bail
1050	22	23.28	7.37	12096	>1000	6.13	249.2	———	surge & Bail
1050	———	well	went	dry	———	———	———	———	———
1105	27	22.42	7.18	12065	>1000	6.60	257.3	———	surge & Bail
1108	30	well	went	dry	———	———	———	———	———
1125	34	22.37	7.19	12135	>1000	6.92	241.2	———	surge & Bail
1130	45	22.03	7.15	12719	908	9.02	249.1	———	surge & Bail
1130	———	Finished	w/	surge &	Bail	———	———	———	———
1200	0	Begin to	pump	well	———	———	———	STWL 20.27	Pumping
1205	5	23.72	6.85	12784	562	4.17	159.2	23.98	5 mins
1215	≈1gpm	23.54	6.91	12872	280	6.51	89.5	28.13	15 mins
1270	≈1gpm	23.99	6.90	12777	204	7.28	109.1	33.12	30 mins
1235	≈35gal	———	well	went	dry	———	———	———	———
1300	———	Resume	pumping	well	———	———	———	STWL 20.68	———

Chemets DO (mg/L): _____

	Method	Container Type/Volume	Preservative
Sample Analyses: →			
Sample Collection Method: ↘			

Pump: [ ] Flow Rate:	Sample ID:	Sample Time:
Bailer: [ ] Type: disposable	Duplicate ID:	Sample Time:
Other: [ ] Desc.:	Equip. blank ID:	Sample Time:

CDM MONITORING WELL PURGE AND SAMPLING FORM

Well No.: AMW6 | Site: Seal Beach | Date: 10/8/07

Time	Gallons	Temp. (°C/°F)	pH	Conductivity (µmhos/cm)	Turbidity (NTUs)	DO (mg/L)	ORP (mV)	DTW (ft TOC)	Comments
10/8									
1305	≈ 1 gpm	23.50	6.82	13083	169	5.27	107.9	25.65	5 mins
1315	≈ 1 gpm	23.71	6.84	12999	176	4.83	90.7	29.42	15 mins
1330	≈ 1 gpm	23.88	6.85	12705	54	6.40	105.1	31.79	30 mins
1345	≈ 1 gpm	23.83	6.84	12634	27	6.92	99.1	33.60	45 mins
1355		Well went Dry							
1420		Resume Pumping						STWL 20.49	
1425	≈ 1 gpm	23.42	6.82	12518	31	3.76	118.2	23.29	5 mins
1440	≈ 1 gpm	23.79	6.84	12601	16	3.82	108.2	31.09	20 mins
1500	≈ 1 gpm	23.87	6.85	12444	38	5.26	99.0	33.34	40 mins
1500		Well Went dry						2 STWL	
1515		Resume Pumping well						21.88	
1520	≈ 1 gpm	23.57	6.81	12981	35	6.89	120.3	27.62	5 mins
1530	≈ 1 gpm	23.48	6.83	12718	28	6.93	113.7	30.30	15 mins
1545	≈ 1 gpm	23.90	6.86	12425	11	8.59	105.3	31.47	30 mins
1600	≈ 1 gpm	23.98	6.83	12349	8	9.04	111.3	33.76	45 mins
1605	125 gal	Stop Pumping For Today							
10/9									
0735		Begin to pump well						STWL 19.06	
0740	≈ 1 gpm	23.02	6.82	12870	82	4.31	126.2	21.37	5 mins
0750	≈ 1 gpm	23.37	6.83	13140	349	5.77	132.7	25.96	15 mins
0805	≈ 1 gpm	23.38	6.85	12887	73	6.42	108.9	30.41	30 mins
0840	≈ 1 gpm	23.56	6.85	12444	14	8.00	108.8	32.59	65 mins
0855	≈ 1 gpm	23.50	6.84	12390	6.8	8.73	110.2	33.46	80 mins
0857		well went Dry							
0920		Resume Pumping well						STWL 20.88	
0925	≈ 1 gpm	23.29	6.81	12823	18	3.06	112.1	24.39	5 mins
0940	≈ 1 gpm	23.42	6.83	12744	13	4.83	113.5	31.25	20 mins
1000	≈ 1 gpm	23.54	6.85	12365	6.8	6.82	110.6	33.37	40 mins
1020	≈ 1 gpm	23.57	6.83	12340	5.2	7.60	113.2	33.68	60 mins
1030		Stop Pumping							
1035		Resume Pumping well						STWL 21.53	
1055	≈ 1 gpm	23.49	6.81	12893	8.1	8.73	113.6	25.35	5 mins
1105	≈ 1 gpm	23.57	6.80	12909	14.9	8.70	118.2	29.27	15 mins
1120	≈ 1 gpm	23.76	6.83	12392	4.2	9.58	116.0	32.55	30 mins
1135	≈ 1 gpm	23.78	6.82	12306	2.6	9.51	115.8	33.48	45 mins
1135	135	Finished Pumping well				Developed			

4" PVC PID = 0.0 ppm

Well No.: PMW1 Site: Seal Beach Date: 10/15/07

Time	Gallons	Temp. (C/F)	pH	Conductivity (µmhos/cm)	Turbidity (NTUs)	DO (mg/L)	ORP (mV)	DTW (ft TOC)	Comments
1400	———	Begin to surge and Bail						STWL 19.82	———
1415	4 gal	21.27	6.94	7469	>1000	11.47	301.6	———	surge & Bail
1420	17 gal	21.59	6.92	11729	>1000	14.28	270.8	———	"
1425	26 gal	21.35	6.86	11656	>1000	15.51	244.0	———	"
1430	30 gal	———	Finished w/ surge & Bail						———
1445	———	——— Begin to Pump well						STWL 20.30'	Pumping
1450	≈ 1 gpm	21.95	6.71	11967	>1000	6.77	66.7	22.26	5 mins
1455	≈ 1 gpm	22.08	6.73	11999	>1000	7.81	82.8	23.04	10 mins
1500	≈ 1 gpm	22.43	6.77	12034	>1000	6.97	84.5	23.85	15 mins
1515	≈ 1 gpm	22.44	6.75	12225	582	6.38	95.8	24.39	30 mins
1530	≈ 1 gpm	22.51	6.74	12104	491	6.08	94.7	24.58	45 mins
1545	≈ 1 gpm	22.35	6.73	12106	104	6.19	103.8	24.76	60 mins
1600	≈ 1 gpm	22.42	6.74	12100	78	6.30	107.2	25.03	75 mins
1600	85 gal	———	Stop Pumping						———
	85 gallons		Removed		Submersible Pump				

4" PVC PID=0.0 ppm

Well No.: PMW9 | Site: Seal Beach | Date: 10/15/07

Time	Gallons	Temp. (C/F)	pH	Conductivity (µmhos/cm)	Turbidity (NTUs)	DO (mg/L)	ORP (mV)	DTW (ft TOC)	Comments
1130	—	Begin to Surge and Bail well						STWL 20.04	—
1155	≈4	21.72	7.04	6090	>1000	11.04	160.2	—	surge & Bail
1201	≈12	21.94	7.10	7058	>1000	12.81	141.0	—	"
1204	≈20	21.60	7.09	6902	>1000	14.88	135.9	—	"
1205	—	Finished w/ surge & Bail							—
1230	—	Begin to Pump well						STWL 28.20	Pumping
1235	5 gal	22.57	6.85	7729	>1000	12.40	89.6	24.37	5 mins
1240	≈1.2 gpm	22.99	6.84	8049	>1000	11.55	77.7	28.27	10 mins
1245	≈1 gpm	23.50	6.87	9149	>1000	11.78	60.3	29.66	15 mins
1300	≈1 gpm	22.93	6.86	9485	898	11.90	69.2	29.99	30 mins
1315	≈1 gpm	23.31	6.86	9433	383	12.39	73.2	30.88	45 mins
1330	≈1 gpm	23.26	6.86	9471	106	12.43	75.8	31.23	60 mins
1330	45 gallons	— Stop Pumping							—

45 gallons Removed

submersible Pump

Appendix E.5
AEW-1 Development

Well No.: AEW1	Site: Seal Beach	Date: 9/20/07
Client:	Project Number:	
Well Casing Diameter (inches): 4"	Well Casing Material: (PVC) SS Other:	
Well Headspace: PID (ppm): 0.0		
Samplers: Chad Marvin with CDM	~~with Blaine Tech~~	
Total Depth of Well (feet): 35.0	2" - 0.16	
Depth to Water (feet): 17.27	(X) 4" - 0.65 Gal/ft. = 11.52	(X) 3 = _____
Water Column Height (feet): 17.73	6" - 1.47	Minimum purge volume (gallons)
Well Reference Point:	"-	

PURGE METHOD: Submersible pump [X]	Bladder pump [ ]	Disposable ba[ ]
Pump Make/Model: 2" Grundfos Rediflo	Depth of pump intake (feet):	
Purge equipment decontaminated? Y [X] N [ ]	Container type: 55 gallon Drum	
Purge/decon water containerized? Y [X] N [ ]	Volume:	

Start Time: 0950 Flow Rate: _____

Time	Gallons	Temp. (°C) °F)	pH	Conductivity (µmhos/cm)	Turbidity (NTUs)	DO (mg/L)	ORP (mV)	DTW (ft TOC)	Comments
1011	≈3	22.54	6.54	4739	>1000	3.99	193.6		Swab & Bail
1019	≈8	22.49	6.50	5076	>1000	3.52	162.8		"
1027	≈20	22.67	6.53	5414	>1000	4.22	163.5		"
1036	≈25	22.59	6.60	5696	>1000	4.42	162.5		"
1045	—	Begin to Pump well			—			STWL 17.31	Pumping
1050	≈1.5gpm	23.28	6.38	5641	545	2.13	114.2	20.48	"
1055	≈20	23.41	6.40	5914	221	0.89	86.0	21.96	"
1100	≈30	23.36	6.40	6001	890	0.70	46.0	21.95	"
1105	≈1.7gpm	23.36	6.39	6009	695	0.69	49.2	21.96	"
1110	≈40	23.41	6.40	6117	122	0.66	27.2	21.97	"
1115	≈1.6gpm	23.43	6.40	6129	183	0.65	27.0	21.97	"
1120	≈60	23.38	6.39	6123	56.7	0.64	48.3	21.94	"
1125	≈1.7gpm	23.39	6.40	6160	45.7	0.64	60.4	22.11	"
1130	70	23.40	6.40	6156	52.0	0.66	63.8	22.10	"

Chemets DO (mg/L): _____

Sample Analyses: →	Analyzed ?	EPA Method	Container Type/Volume	Preservative
Sample Collection Method: ↙				

Pump: [X] Flow Rate:	Sample ID:	Sample Time:
Bailer: [X] Type: ~~disposable~~ stainless steel	Duplicate ID:	Sample Time:
Other: [ ] Desc.:	Equip. blank ID:	Sample Time:

CDM MONITORING WELL PURGE AND SAMPLING FORM

Well No.: AEW1	Site:	Date: 9/21/07
Client:	Project Number:	
Well Casing Diameter (inches):	Well Casing Material: PVC SS Other:	
Well Headspace: PID (ppm):		
Samplers: with CDM		with Blaine Tech

Total Depth of Well (feet): _____ 2" - 0.16

Depth to Water (feet): _____ (X) 4" - 0.65 Gal/ft. = _____ (X) 3 = _____ Minimum purge volume (gallons)

Water Column Height (feet): _____ 6" - 1.47

Well Reference Point: __" - ____

PURGE METHOD: Submersible pump ☐ Bladder pump ☐ Disposable ba ☐	
Pump Make/Model: 2" Grundfos Rediflo	Depth of pump intake (feet):
Purge equipment decontaminated? Y ☐ N ☐	Container type:
Purge/decon water containerized? Y ☐ N ☐	Volume:

Start Time: _____ Flow Rate: _____

Time	Gallons	Temp. (°C)°F)	pH	Conductivity (µmhos/cm)	Turbidity (NTUs)	DO (mg/L)	ORP (mV)	DTW (ft TOC)	Comments
1140	≈ 1.5gpm	23.94	6.44	6230	176	1.50	87.6	20.54	Pumping
1200	≈ 2gpm	23.61	6.39	6110	189	0.71	93.6	22.13	Pump & Surge
1220	≈ 2gpm	23.53	6.40	6115	148	1.07	174.2	23.01	"
1231	≈ 90	23.21	6.38	5315	85.4	1.08	1125	23.41	"
1246	≈ 2gpm	23.26	6.39	5830	119	1.04	105.4	23.91	"
1250	≈ 2gpm	23.19	6.42	6641	183	0.84	108.7	22.4	After surge
1300	≈ 150	23.34	6.40	6389	83.2	0.71	102.6	24.11	"
1308	≈ 2gpm	23.33	6.43	7180	290	0.56	115.1	21.38	After surge
1320	≈ 2gpm	23.33	6.40	6451	104	0.76	105.2	24.27	During
1326	≈ 195	23.37	6.41	6287	103	1.05	97.9	20.63	After surge
1341	≈ 2gpm	23.40	6.40	6416	65.3	0.75	93.6	24.23	During
1345	≈ 220	23.69	6.46	6753	89.2	2.32	111.6	20.62	After surge
1400	≈ 2gpm	23.41	6.40	6355	125	0.96	110.4	23.92	During
1430	≈ 235	23.42	6.40	6467	45.2	0.85	112.2	24.18	During
1455	≈ 270	23.40	6.39	6415	39.9	0.86	115.2	24.04	During

Chemets DO (mg/L): _____

Sample Analyses: →	Analyzed ?	EPA Method	Container Type/Volume	Preservative
Sample Collection Method: ↙				

Pump: ☐ Flow Rate:	Sample ID:	Sample Time:
Bailer: ☐ Type: disposable	Duplicate ID:	Sample Time:
Other: ☐ Desc.:	Equip. blank ID:	Sample Time:

CDM MONITORING WELL PURGE AND SAMPLING FORM

Well No.: AEW1	Site:	Date:
Client:	Project Number:	
Well Casing Diameter (inches):	Well Casing Material: PVC SS Other:	
Well Headspace: PID (ppm):		
Samplers: with CDM		with Blaine Tech

Total Depth of Well (feet): _____ 2" - 0.16

Depth to Water (feet): _____ (X) 4" - 0.65 Gal/ft. = _____ (X) 3 = _____

Water Column Height (feet): _____ 6" - 1.47 ← Minimum purge volume (gallons)

Well Reference Point: __" - ____

PURGE METHOD: Submersible pump ☐ Bladder pump ☐ Disposable ba ☐

Pump Make/Model: 2" Grundfos Rediflo	Depth of pump intake (feet):
Purge equipment decontaminated? Y ☐ N ☐	Container type:
Purge/decon water containerized? Y ☐ N ☐	Volume:

Start Time: _____ Flow Rate: _____

Time	Gallons	Temp. (°C/°F)	pH	Conductivity (µmhos/cm)	Turbidity (NTUs)	DO (mg/L)	ORP (mV)	DTW (ft TOC)	Comments
1507	≈2gpm	23.52	6.41	6203	54.2	1.07	125.3	22.22	After surge
1520	≈2gpm	23.40	6.41	6725	42.7	0.99	118.1	24.12	During
1538	≈320	23.43	6.39	6727	95.6	1.58	105.9	23.47	During
1559	≈335	23.44	6.39	6535	59.4	0.90	100.6	23.68	During
1600	—	stop	Pumping for Today	—	—	—	—	—	—

Chemets DO (mg/L):_____

Sample Analyses: →	Analyzed ?	EPA Method	Container Type/Volume	Preservative
Sample Collection Method: ↙				

Pump: ☐ Flow Rate:	Sample ID:	Sample Time:
Bailer: ☐ Type: disposable	Duplicate ID:	Sample Time:
Other: ☐ Desc.:	Equip. blank ID:	Sample Time:

CDM MONITORING WELL PURGE AND SAMPLING FORM

Appendix F
Injection Details

ESTCP Project ER-0513,
NAVAL WEAPONS STATION SEAL BEACH, SITE 70
ACTIVE CELL INJECTION SUMMARY

Injection Event	Well ID	Injection Date Range	Volume Water Injected (gallons)	Volume 60% Sodium Lactate Injected (gallons)	Sodium Lactate Conc. (%)	Volume Lactate Injected [1] (gallons)	Lactate Injection Conc. (%)	Total Injection Time (Hours)	Average Lactate Injection Flowrate (gpm)	Comments
PRE-CONDITIONING										
1	AIW-1	4/23-4/24/08	445	23	5.3%	11	2.5%	10.0	0.7	
	AIW-2	4/23-4/24/09	505	27	5.3%	13	2.5%	10.0	0.8	
	TOTAL	**4/23-4/24/10**	**950**	**50**	**5.3%**	**24**	**2.5%**	**10.0**	**1.6**	
2	AIW-1	7/16-18/08	408	22	5.5%	11	2.6%	16.0	0.7	
	AIW-2	7/16-18/08	577	28	4.8%	13	2.3%	16.0	0.7	
	TOTAL	**7/16-18/08**	**985**	**50**	**5.1%**	**24**	**2.4%**	**16.0**	**1.0**	
3	AIW-1	10/17-21/2008	734	24	3.3%	12	1.6%	17.5	0.7	Active system run for 16 hours following injection
	AIW-2	10/17-21/2008	800	26	3.2%	12	1.5%	17.5	0.6	Active system run for 16 hours following injection
	TOTAL	**10/17-21/2008**	**1,534**	**50**	**3.3%**	**24**	**1.6%**	**17.5**	**1.5**	
4	AIW-1	1/6-8/09	756	26	3.5%	13	1.7%	17.0	0.7	
	AIW-2	1/6-8/09	625	21	3.4%	10	1.6%	17.0	0.8	
	TOTAL	**1/6-8/09**	**1,381**	**48**	**3.4%**	**23**	**1.7%**	**17.0**	**1.4**	
PRE-CONDITIONING TOTALS										
		AIW-1	**2,343**	**96**	4.1%	**46**	**2.0%**	**60.5**	0.6	
		AIW-2	**2,507**	**101**	4.0%	**49**	**1.9%**	**60.5**	0.7	
		TOTAL	**4,850**	**198**	**4.1%**	**95**	**2.0%**	**60.5**	**1.3**	
BIOAUGMENTATION										
1	AIW-1	1/30/09	648	12.9	2.0%	6.2	1.0%	9.5	1.1	Switched to weekly injections
	AIW-2	1/30/09	593	11.9	2.0%	5.7	1.0%	9.5	1.0	See separate spreadsheet for details:
	TOTAL	**1/30/09**	**1,241**	**24.8**	**2.0%**	**11.9**	**1.0%**	**9.5**	**2.2**	(0109 Active Injection Log.xls)
2	AIW-1	2/5/09	428	6.9	1.6%	3.3	0.8%	6.5	1.1	See separate spreadsheet for details:
	AIW-2	2/5/09	376	6.0	1.6%	2.9	0.8%	6.5	1.0	(0209 Active Injection Log.xls)
	TOTAL	**2/5/09**	**804**	**12.9**	**1.6%**	**6.2**	**0.8%**	**6.5**	**2.1**	
3	AIW-1	2/13/09	337	6.2	1.8%	3.0	0.9%	6.0	0.9	
	AIW-2	2/13/09	345	6.3	1.8%	3.0	0.9%	6.0	1.0	
	TOTAL	**2/13/09**	**682**	**12.5**	**1.8%**	**6.0**	**0.9%**	**6.0**	**1.9**	
4	AIW-1	2/20/09	359	6.1	1.7%	2.9	0.8%	7.5	0.8	
	AIW-2	2/20/09	394	6.6	1.7%	3.2	0.8%	7.5	0.9	
	TOTAL	**2/20/09**	**753**	**12.7**	**1.7%**	**6.1**	**0.8%**	**7.5**	**1.7**	
5	AIW-1	2/27/09	391	5.6	1.4%	2.7	0.7%	7.8	0.8	
	AIW-2	2/27/09	485	6.9	1.4%	3.3	0.7%	7.8	1.0	
	TOTAL	**2/27/09**	**876**	**12.5**	**1.4%**	**6.0**	**0.7%**	**7.8**	**1.9**	
FEBRUARY TOTALS			**4,356**	**75**	**1.7%**	**36**	**0.8%**	**37**	**1.9**	
6	AIW-1	3/5/09	319	5.7	1.8%	2.8	0.9%	6.5	0.8	See separate spreadsheet for details:
	AIW-2	3/5/09	382	6.9	1.8%	3.3	0.9%	6.5	1.0	(0309 Active Injection Log.xls)
	TOTAL	**3/5/09**	**701**	**12.6**	**1.8%**	**6.0**	**0.9%**	**6.5**	**1.8**	
7	AIW-1	3/13/09	385	5.8	1.5%	2.8	0.7%	7.0	0.9	
	AIW-2	3/13/09	451	6.9	1.5%	3.3	0.7%	7.0	1.1	
	TOTAL	**3/13/09**	**836**	**12.7**	**1.5%**	**6.1**	**0.7%**	**7.0**	**2.0**	

ESTCP Project ER-0513,
NAVAL WEAPONS STATION SEAL BEACH, SITE 70
ACTIVE CELL INJECTION SUMMARY

Injection Event	Well ID	Injection Date Range	Volume Water Injected (gallons)	Volume 60% Sodium Lactate Injected (gallons)	Sodium Lactate Conc. (%)	Volume Lactate Injected [1] (gallons)	Lactate Injection Conc. (%)	Total Injection Time (Hours)	Average Lactate Injection Flowrate (gpm)	Comments
8	AIW-1	3/20/09	456	6.9	1.5%	3.3	0.7%	7.0	1.1	
	AIW-2	3/20/09	377	5.7	1.5%	2.7	0.7%	7.0	0.9	
	TOTAL	**3/20/09**	**833**	**12.6**	**1.5%**	**6.0**	**0.7%**	**7.0**	**2.0**	
9	AIW-1	3/27/09	419	5.6	1.3%	2.7	0.6%	7.0	1.0	
	AIW-2	3/27/09	495	6.7	1.3%	3.2	0.6%	7.0	1.2	
	TOTAL	**3/27/09**	**914**	**12.3**	**1.3%**	**5.9**	**0.6%**	**7.0**	**2.2**	
MARCH TOTALS			**3,284**	**50**	**1.5%**	**24**	**0.7%**	**28**	**2.0**	
10	AIW-1	4/2/09	285	7.1	2.5%	3.4	1.2%	7.3	0.6	See separate spreadsheet for details:
	AIW-2	4/2/09	228	5.6	2.5%	2.7	1.2%	7.3	0.5	(0409 Active Injection Log.xls)
	TOTAL	**4/2/09**	**513**	**12.7**	**2.5%**	**6.1**	**1.2%**	**7.3**	**1.2**	
11	AIW-1	4/8/09	383	6.8	1.8%	3.3	0.9%	5.7	1.1	
	AIW-2	4/8/09	327	5.8	1.8%	2.8	0.9%	5.7	1.0	
	TOTAL	**4/8/09**	**710**	**12.6**	**1.8%**	**6.0**	**0.9%**	**5.7**	**2.1**	
12	AIW-1	4/18/09	333	6.2	1.9%	3.0	0.9%	6.0	0.9	
	AIW-2	4/18/09	331	6.2	1.9%	3.0	0.9%	6.0	0.9	
	TOTAL	**4/18/09**	**664**	**12.4**	**1.9%**	**6.0**	**0.9%**	**6.0**	**1.8**	
13	AIW-1	4/24/09	396	6.6	1.7%	3.1	0.8%	6.0	1.1	
	AIW-2	4/24/09	341	5.6	1.7%	2.7	0.8%	6.0	0.9	
	TOTAL	**4/24/09**	**737**	**12.2**	**1.7%**	**5.9**	**0.8%**	**6.0**	2.0	
APRIL TOTALS			**2,624**	**50**	**1.9%**	**24**	**0.9%**	**25**	**1.8**	
14	AIW-1	5/1/09	398	6.6	1.6%	3.2	0.8%	6.0	1.1	See separate spreadsheet for details:
	AIW-2	5/1/09	360	5.9	1.6%	2.8	0.8%	6.0	1.0	(0509 Active Injection Log.xls)
	TOTAL	**5/1/09**	**758**	**12.5**	**1.6%**	**6.0**	**0.8%**	**6.0**	**2.1**	
15	AIW-1	5/7/09	463	7.3	1.6%	3.5	0.8%	7.0	1.1	
	AIW-2	5/7/09	325	5.2	1.6%	2.5	0.8%	7.0	0.8	
	TOTAL	**5/7/09**	**788**	**12.5**	**1.6%**	**6.0**	**0.8%**	**7.0**	**1.9**	
16	AIW-1	5/15/09	458	6.6	1.4%	3.2	0.7%	7.0	1.1	
	AIW-2	5/15/09	420	6.1	1.4%	2.9	0.7%	7.0	1.0	
	TOTAL	**5/15/09**	**878**	**12.7**	**1.4%**	**6.1**	**0.7%**	**7.0**	**2.1**	
17	AIW-1	5/22/09	444	6.3	1.4%	3.0	0.7%	9.0	0.8	
	AIW-2	5/22/09	450	6.3	1.4%	3.0	0.7%	9.0	0.8	
	TOTAL	**5/22/09**	**894**	**12.6**	**1.4%**	**6.0**	**0.7%**	**9.0**	**1.7**	
18	AIW-1	5/29/09	442	7.0	1.6%	3.3	0.8%	7.8	0.9	
	AIW-2	5/29/09	352	5.5	1.6%	2.7	0.8%	7.8	0.7	
	TOTAL	**5/29/09**	**794**	**12.5**	**1.6%**	**6.0**	**0.8%**	**7.8**	**1.7**	
MAY TOTALS			**4,112**	**63**	**1.5%**	**30**	**0.7%**	**37**	**1.9**	
19	AIW-1	6/3/09	421	6.9	1.6%	3.3	0.8%	6.0	1.2	See separate spreadsheet for details:
	AIW-2	6/3/09	356	5.8	1.6%	2.8	0.8%	6.0	1.0	(0609 Active Injection Log.xls)
	TOTAL	**6/3/09**	**777**	**12.7**	**1.6%**	**6.1**	**0.8%**	**6.0**	**2.2**	
20	AIW-1	6/9/09	337	6.6	1.9%	3.1	0.9%	5.0	1.1	
	AIW-2	6/9/09	300	5.8	1.9%	2.8	0.9%	5.0	1.0	

ESTCP Project ER-0513,
NAVAL WEAPONS STATION SEAL BEACH, SITE 70
ACTIVE CELL INJECTION SUMMARY

Injection Event	Well ID	Injection Date Range	Volume Water Injected (gallons)	Volume 60% Sodium Lactate Injected (gallons)	Sodium Lactate Conc. (%)	Volume Lactate Injected [1] (gallons)	Lactate Injection Conc. (%)	Total Injection Time (Hours)	Average Lactate Injection Flowrate (gpm)	Comments
	TOTAL	**6/9/09**	**637**	**12.4**	**1.9%**	**6.0**	**0.9%**	**5.0**	**2.1**	
21	AIW-1	6/20/09	529	25.9	4.9%	12.4	2.3%	7.0	1.3	**Injection volume changed to 50 gallons
	AIW-2	6/20/09	491	24.0	4.9%	11.5	2.3%	7.0	1.2	
	TOTAL	**6/20/09**	**1,020**	**49.9**	**4.9%**	**24.0**	**2.3%**	**7.0**	**2.4**	
22	AIW-1	6/26/09	378	24.7	6.5%	11.8	3.1%	5.0	1.3	
	AIW-2	6/26/09	391	25.5	6.5%	12.3	3.1%	5.0	1.3	
	TOTAL	**6/26/09**	**769**	**50.2**	**6.5%**	**24.1**	**3.1%**	**5.0**	**2.6**	
JUNE TOTALS			**3,203**	**125**	**3.8%**	**60**	**1.8%**	**23**	**2.3**	
23	AIW-1	7/2/09	484	23.8	4.9%	11.4	2.4%	15.2	0.5	See separate spreadsheet for details:
	AIW-2	7/2/09	541	26.5	4.9%	12.7	2.4%	15.2	0.6	(0709 Active Injection Log.xls)
	TOTAL	**7/2/09**	**1,025**	**50.3**	**4.9%**	**24.1**	**2.4%**	**15.2**	**1.1**	
24	AIW-1	7/9/09	521	27.1	5.2%	13.0	2.5%	13.8	0.6	
	AIW-2	7/9/09	446	23.2	5.2%	11.1	2.5%	13.8	0.5	
	TOTAL	**7/9/09**	**967**	**50.3**	**5.2%**	**24.1**	**2.5%**	**13.8**	**1.2**	
25	AIW-1	7/17/09	498	25.1	5.0%	12.0	2.4%	9.8	0.8	
	AIW-2	7/17/09	505	25.4	5.0%	12.2	2.4%	9.8	0.9	
	TOTAL	**7/17/09**	**1,003**	**50.5**	**5.0%**	**24.2**	**2.4%**	**9.8**	**1.7**	
26	AIW-1	7/24/09	361	25.9	7.2%	12.4	3.4%	11.0	0.5	
	AIW-2	7/24/09	343	24.6	7.2%	11.8	3.4%	11.0	0.5	
	TOTAL	**7/24/09**	**704**	**50.5**	**7.2%**	**24.2**	**3.4%**	**11.0**	**1.1**	
27	AIW-1	7/29/09	436	26.2	6.0%	12.6	2.9%	11.0	0.7	
	AIW-2	7/29/09	405	24.3	6.0%	11.7	2.9%	11.0	0.6	
	TOTAL	**7/29/09**	**841**	**50.5**	**6.0%**	**24.2**	**2.9%**	**11.0**	**1.3**	
JULY TOTALS			**4,540**	**252**	**5.7%**	**121**	**2.7%**	**61**	**1.3**	
28	AIW-1	8/7/09	346	22.4	6.5%	10.8	3.1%	10.3	0.6	See separate spreadsheet for details:
	AIW-2	8/7/09	434	28.1	6.5%	13.5	3.1%	10.3	0.7	(0809 Active Injection Log.xls)
	TOTAL	**8/7/09**	**780**	**50.5**	**6.5%**	**24.2**	**3.1%**	**10.3**	**1.3**	
29	AIW-1	8/14/09	458	24.3	5.3%	11.7	2.5%	16.0	0.5	
	AIW-2	8/14/09	483	25.6	5.3%	12.3	2.5%	16.0	0.5	
	TOTAL	**8/14/09**	**941**	**49.9**	**5.3%**	**24.0**	**2.5%**	**16.0**	**1.0**	
30	AIW-1	8/21/09	469	24.1	5.1%	11.6	2.5%	12.2	0.6	
	AIW-2	8/21/09	507	26.0	5.1%	12.5	2.5%	12.2	0.7	
	TOTAL	**8/21/09**	**976**	**50.1**	**5.1%**	**24.0**	**2.5%**	**12.2**	**1.3**	
31	AIW-1	8/28/09	426	22.4	5.2%	10.7	2.5%	14.0	0.5	
	AIW-2	8/28/09	521	27.3	5.2%	13.1	2.5%	14.0	0.6	
	TOTAL	**8/28/09**	**947**	**49.7**	**5.2%**	**23.9**	**2.5%**	**14.0**	**1.1**	
AUGUST TOTALS			**3,644**	**200**	**5.5%**	**96**	**2.7%**	**53**	**1.2**	
32	AIW-1	9/3/09	536	31.4	5.9%	15.1	2.8%	9.0	1.0	See separate spreadsheet for details:
	AIW-2	9/3/09	319	18.7	5.9%	9.0	2.8%	9.0	0.6	(0909 Active Injection Log.xls)
	TOTAL	**9/3/09**	**855**	**50.1**	**5.9%**	**24.0**	**2.8%**	**9.0**	**1.6**	
	AIW-1	9/11/09	-	-	-	-	-	2.0	-	System power outage. System restarted on 9/11/09

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NAVAL WEAPONS STATION SEAL BEACH, SITE 70
ACTIVE CELL INJECTION SUMMARY

Injection Event	Well ID	Injection Date Range	Volume Water Injected (gallons)	Volume 60% Sodium Lactate Injected (gallons)	Sodium Lactate Conc. (%)	Volume Lactate Injected [1] (gallons)	Lactate Injection Conc. (%)	Total Injection Time (Hours)	Average Lactate Injection Flowrate (gpm)	Comments
33	AIW-2	9/11/09	-	-	-	-	-	2.0	-	temporarily but was again shut down after not working properly. System fixed and restarted on 9/17/09.
	TOTAL	**9/11/09**	**-**	**9.8**	**-**	**4.7**	**-**	**2.0**	**-**	
34	AIW-1	9/17/09	470	25.9	5.5%	12.4	2.6%	8.0	1.0	
	AIW-2	9/17/09	277	15.2	5.5%	7.3	2.6%	8.0	0.6	
	TOTAL	**9/17/09**	**747**	**41.1**	**5.5%**	**19.7**	**2.6%**	**8.0**	**1.6**	
35	AIW-1	9/18/09	571	32.3	5.7%	15.5	2.7%	10.0	1.0	
	AIW-2	9/18/09	324	18.3	5.7%	8.8	2.7%	10.0	0.5	
	TOTAL	**9/18/09**	**895**	**50.6**	**5.7%**	**24.3**	**2.7%**	**10.0**	**1.5**	
36	AIW-1	9/25/09	483	30.2	6.2%	14.5	3.0%	14.0	0.6	
	AIW-2	9/25/09	326	20.3	6.2%	9.8	3.0%	14.0	0.4	
	TOTAL	**9/25/09**	**809**	**50.5**	**6.2%**	**24.2**	**3.0%**	**14.0**	**1.0**	
SEPTEMBER TOTALS			**3,306**	**202**	**5.8%**	**92**	**2.8%**	**41**	**1.4**	
37	AIW-1	10/2/09	321	19.7	6.1%	9.4	2.9%	9.0	0.6	
	AIW-2	10/2/09	374	22.9	6.1%	11.0	2.9%	9.0	0.7	
	TOTAL	**10/2/09**	**695**	**42.6**	**6.1%**	**20.4**	**2.9%**	**9.0**	**1.3**	
OCTOBER TOTALS			**695**	**43**	**6.1%**	**20**	**2.9%**	**9**	**1.3**	
			13,974	797	5.7%	378	2.7%	175	1.3	
POST-BIOAGUMENTATION TOTALS										
	AIW-1		15,389	547	3.6%	262	1.7%	313	0.8	
	AIW-2		14,375	504	3.5%	242	1.7%	313	0.8	
	TOTAL		**29,764**	**1,061**	**3.6%**	**504**	**1.7%**	**313**	**1.6**	
OVERALL TOTALS (PRE-CONDITIONING & POST-BIOAUGMENTATION)										
	AIW-1		17,732	643	3.6%	309	1.7%	373	0.8	
	AIW-2		16,882	605	3.6%	290	1.7%	373	0.8	
	TOTAL		**34,614**	**1,258**	**3.6%**	**599**	**1.7%**	**373**	**1.5**	

ESTCP Project ER-0513,
NAVAL WEAPONS STATION SEAL BEACH, SITE 70
PASSIVE CELL INJECTION SUMMARY

Injection Event	Well ID	Injection Date Range	Volume Water Injected (gallons)	Volume 60% Sodium Lactate Injected (gallons)	Sodium Lactate Conc. (%)	Volume Lactate Injected [1] (gallons)	Lactate Injection Conc. (%)	Total Injection Time (Hours)	Average Lactate Injection Flowrate (gpm)	Comments
Pre-Conditioning										
1	PIW-1	8/7-8/8/08	924	16.5	1.8%	7.9	0.9%	14.5	1.1	Tracer performed in PIW-1 during this injection.
	PIW-2	8/7-8/8/08	1,066	17.0	1.6%	8.2	0.8%	12.3	1.5	
	PIW-3	8/7-8/8/08	1,066	17.0	1.6%	8.2	0.8%	12.3	1.5	
	TOTAL	**8/7-8/8/08**	**3,057**	**51**	**1.7%**	**24**	**0.8%**	**14.5**	**3.5**	
2	PIW-1	9/8-9/9/08	1,067	17.0	1.6%	8.1	0.8%	16.2	1.1	
	PIW-2	9/8-9/9/08	1,071	17.0	1.6%	8.2	0.8%	13.3	1.3	
	PIW-3	9/8-9/9/08	1,067	17.0	1.6%	8.1	0.8%	13.3	1.3	
	TOTAL	**9/8-9/9/08**	**3,205**	**51**	**1.6%**	**24**	**0.8%**	**16.2**	**3.3**	
3	PIW-1	10/21-22/08	1,067	17	1.6%	8	0.8%	18.0	1.0	
	PIW-2	10/21-22/08	1,066	17	1.6%	8	0.8%	18.0	1.0	
	PIW-3	10/21-22/08	1,066	17	1.6%	8	0.8%	18.0	1.0	
	TOTAL	**10/21-22/08**	**3,199**	**52**	**1.6%**	**25**	**0.8%**	**18.0**	**3.0**	
4	PIW-1	1/6-8/09	953	15.8	1.7%	7.6	0.8%	15.9	1.0	
	PIW-2	1/6-8/09	954	15.8	1.7%	7.6	0.8%	15.9	1.0	
	PIW-3	1/6-8/09	952	15.8	1.7%	7.6	0.8%	15.9	1.0	
	TOTAL	**1/6-8/09**	**2,859**	**48**	**1.7%**	**23**	**0.8%**	**15.9**	**3.0**	
Pre-Conditioning Totals	PIW-1	8/7/08-1/12/09	4,011	67	1.7%	32	0.8%	65	1.0	
	PIW-2	8/7/08-1/12/09	4,156	67	1.6%	32	0.8%	60	1.2	
	PIW-3	8/7/08-1/12/09	4,151	67	1.6%	32	0.8%	60	1.2	
	TOTAL	**8/7/08-1/12/09**	**12,319**	**201**	**1.6%**	**96**	**0.8%**	**65**	**3.2**	
POST-BIOAUGMENTATION										
1	PIW-1	2/4-2/6/09	1,001	16.7	1.7%	8.0	0.8%	17.2	1.0	
	PIW-2	2/4-2/6/09	1,001	16.7	1.7%	8.0	0.8%	17.2	1.0	
	PIW-3	2/4-2/6/09	1,000	16.7	1.7%	8.0	0.8%	17.2	1.0	
	TOTAL	**2/4-2/6/09**	**3,002**	**50**	**1.7%**	**24.0**	**0.8%**	**17.2**	**2.9**	
2	PIW-1	3/2-3/5/09	1,000	16.6	1.7%	8.0	0.8%	16.8	1.0	
	PIW-2	3/2-3/5/09	1,006	16.7	1.7%	8.0	0.8%	16.8	1.0	
	PIW-3	3/2-3/5/09	1,007	16.7	1.7%	8.0	0.8%	16.8	1.0	
	TOTAL	**3/2-3/5/09**	**3,013**	**50**	**1.7%**	**24.0**	**0.8%**	**16.8**	**3.0**	
3	PIW-1	4/1-4/2/09	1,000	16.6	1.7%	8.0	0.8%	17.7	0.9	
	PIW-2	4/1-4/2/09	1,002	16.7	1.7%	8.0	0.8%	17.7	0.9	
	PIW-3	4/1-4/2/09	1,005	16.7	1.7%	8.0	0.8%	17.7	0.9	
	TOTAL	**4/1-4/2/09**	**3,007**	**50**	**1.7%**	**24.0**	**0.8%**	**17.7**	**2.8**	
4	PIW-1	5/5-5/7/09	1,000	16.7	1.7%	8.0	0.8%	16.6	1.0	
	PIW-2	5/5-5/7/09	1,000	16.7	1.7%	8.0	0.8%	16.6	1.0	
	PIW-3	5/5-5/7/09	1,001	16.7	1.7%	8.0	0.8%	16.6	1.0	
	TOTAL	**5/5-5/7/09**	**3,001**	**50**	**1.7%**	**24.0**	**0.8%**	**16.6**	**3.0**	
	PIW-1	6/1-6/3/09	1,000	16.6	1.7%	8.0	0.8%	18.0	0.9	

ESTCP Project ER-0513,
NAVAL WEAPONS STATION SEAL BEACH, SITE 70
PASSIVE CELL INJECTION SUMMARY

Injection Event	Well ID	Injection Date Range	Volume Water Injected (gallons)	Volume 60% Sodium Lactate Injected (gallons)	Sodium Lactate Conc. (%)	Volume Lactate Injected [1] (gallons)	Lactate Injection Conc. (%)	Total Injection Time (Hours)	Average Lactate Injection Flowrate (gpm)	Comments
5	PIW-2	6/1-6/3/09	1,001	16.7	1.7%	8.0	0.8%	18.0	0.9	
	PIW-3	6/1-6/3/09	1,003	16.7	1.7%	8.0	0.8%	18.0	0.9	
	TOTAL	**6/1-6/3/09**	**3,004**	**50**	**1.7%**	**24.0**	**0.8%**	**18.0**	**2.8**	
6	PIW-1	6/30-7/2/09	1,197	20.5	1.7%	9.8	0.8%	20.7	1.0	
	PIW-2	6/30-7/2/09	1,152	19.7	1.7%	9.8	0.8%	20.7	0.9	
	PIW-3	6/30-7/2/09	1,161	19.8	1.7%	9.8	0.8%	20.7	0.9	
	TOTAL	**6/30-7/2/09**	**3,510**	**60**	**1.7%**	**28.8**	**0.8%**	**20.7**	**2.8**	
7	PIW-1	8/19-8/21/09	1,117	19.4	1.7%	9.3	0.8%	18.5	1.0	
	PIW-2	8/19-8/21/09	1,158	20.2	1.7%	9.3	0.8%	18.5	1.0	
	PIW-3	8/19-8/21/09	1,172	20.4	1.7%	9.3	0.8%	18.5	1.1	
	TOTAL	**8/19-8/21/09**	**3,447**	**60**	**1.7%**	**28.8**	**0.8%**	**18.5**	**3.1**	
8	PIW-1	9/1-9/3/09	1,166	19.6	1.7%	9.4	0.8%	18.0	1.1	
	PIW-2	9/1-9/3/09	1,200	20.2	1.7%	9.4	0.8%	18.0	1.1	
	PIW-3	9/1-9/3/09	1,200	20.2	1.7%	9.4	0.8%	18.0	1.1	
	TOTAL	**9/1-9/3/09**	**3,566**	**60**	**1.7%**	**28.8**	**0.8%**	**18.0**	**3.3**	
Post-Bioaugmentation Totals										
	PIW-1		8,481	143	1.7%	69	0.8%	143	1.0	
	PIW-2		8,519	143	1.7%	69	0.8%	143	1.0	
	PIW-3		8,549	144	1.7%	69	0.8%	143	1.0	
	TOTAL		**25,549**	**430**	**1.7%**	**206**	**0.8%**	**143**	**3.0**	
Overall Totals (Pre-Conditioning & Post-Bioaugmentation)										
	PIW-1		12,492	209	1.7%	101	0.8%	208	1.0	
	PIW-2		12,675	211	1.7%	101	0.8%	203	1.0	
	PIW-3		12,701	211	1.7%	101	0.8%	203	1.0	
	TOTAL		37,868	631	**1.7%**	303	**0.8%**	208	**3.0**	

Appendix G
Sampling Methods Supplemental Information and Quality Assurance Information

Appendix G – Quality Assurance and Quality Control Procedures

G.1 Calibration Procedures, Quality Control Checks, and Corrective Action

The purpose of this section is to provide a summary of the specific maintenance/calibration procedures for all equipment related to the collection of data either in the field or through laboratory analysis of samples during completion of the project.

G.1.1 Laboratory Equipment Calibration

Calibration procedures for laboratory instruments are found in each laboratory's QA Manual. Calibration for analyses performed by offsite laboratories were defined by the analytical methods. Data reduction and validation for the laboratory data and for the final reporting were described in the laboratory's QA Manual.

G.1.2 Field Instrumentation

Field instrumentation was used to provide data concerning health and safety considerations and as a method for field screening samples.

G.1.2.1 Photoionization Detector

Calibration of the instrument was performed with a factory supplied calibration kit according to the manufacturer's specifications. Calibration was performed daily as a part of routine instrument maintenance, with a calibration record being maintained in the field manager's logbook.

G.1.2.2 HACH Kits

HACH kits were used to measure concentrations of specific parameters in the field. Vendor instructions for use of these kits were followed and documented; kits were calibrated by the vendor and do not require calibration by the user. This includes the operation of the HACH DR2000 spectrometer.

G.1.2.3 Multi-parameter Water Quality Instrument

The mutli-parameter Water Quality Instrument is a specially designed vessel that allows simultaneous measurement of water quality parameters as fresh flowing water is passed through the cell. For this field work, the instrument was used to measure temperature, conductivity, pH, redox potential (Eh), and DO. Calibration was performed in accordance with instrument procedures requiring fresh calibration solutions. Instruments were rented for this demonstration project, and were properly calibrated by the vendor. However, field calibration was performed as necessary when parameter drift or malfunction was noted. Field calibration was recorded in the field logbook.

G.2 Quality Assurance Sampling

G.2.1 Accuracy

For this demonstration, accuracy of laboratory results was assessed using the analytical results of method-defined surrogates, laboratory control samples, matrix spikes, and calibration standards. The percent recovery (%R) was calculated using the following equations:

$$\%R = \frac{A - B}{C} \times 100$$

where: A = Analyte concentration determined experimentally in the spiked sample;
B = Analyte concentration determined by a separate analysis of the unspiked sample; and,
C = concentration of spiked analyte.

The only parameters that required matrix spikes are the VOC samples sent to an offsite laboratory. The accuracy goal for these samples was a percent recovery of 70-130%. The accuracy goal for all field and trip blanks was no detections of analytes in these samples.

G.2.2 Precision

Precision was assessed by calculating the relative percent difference (RPD) between the field duplicate samples. The RPD was calculated for each pair of duplicates using the following equation:

$$\%RPD = \frac{S - D}{(S + D)/2} \times 100$$

where: S = First sample value
D = Second sample value (duplicate value)

The precision goal for this project for sample pairs whose values are both greater than 10X the MDL limit was an RPD $\leq$ 25%. For sample pairs that have one or both values less than 10X the MDL, the precision goal was RPD $\leq$ 50%. Sample pairs that have one or both values that are less than the MDL did not have RPDs calculated.

G.2.3 Completeness

Completeness of data was assessed as the percentage amount of valid data compared to the total amount of expected data using the following equation:

$$\%Completeness = \frac{Valid\ Data\ Obtained}{Total\ Data\ Planned} \times 100$$

The completeness goal for this project was 90% of all planned samples, as defined in the Demonstration Plan. Completeness was tracked both for individual sampling rounds and cumulatively over the course of the demonstration.

G.2.4 Representativeness

Representativeness expresses the degree to which data accurately and precisely represent a characteristic of a population and parameter variations at a sampling point, a process condition, or an environmental condition. Representativeness is a qualitative parameter that is dependent on the proper design of the sampling program and proper laboratory protocol. The sampling program was described in Section 3.7.6 of the Demonstration Plan.

Representativeness of the data was assessed by the Project Manager and the QA Coordinator through review and comparison of the applicable data (field and laboratory duplicates, spikes, blanks) and by verifying that the sampling and analysis plan/design set forth in the Demonstration Plan was followed for all data generated during the project activities.

G.2.5 Comparability

Comparability expresses the confidence with which one data set can be compared with another. The extent of comparability between existing and planned analytical data depends in part on the similarity of sampling and analytical methods. The procedures used to obtain the planned analytical data, as documented in the QAPP, were expected to provide comparable data for these project activities.

G.3 Equipment Decontamination

Equipment decontamination was performed for all intrusive instruments that were not dedicated equipment. Decontamination of drilling equipment, including steam cleaning, was performed during well installation. Additionally, decontamination of field instruments that were not dedicated to the wells was performed in between wells utilizing Alconox and distilled water.

G.4 Documentation of Sample Collection

All sample collection was documented as described in the QAPP. The following information, as applicable, was recorded.

- Custody and Document Control
- Chain-of-custody from field to laboratory
- Laboratory custody through designated laboratory-sample custodian
- Sample designation number(s)
- Identity of sampler
- Date of sample collection, shipping, and laboratory analysis
- Physical Data Elements
- Sampling date and time
- Sampling location and description
- Sample collection technique
- Field preparation techniques (e.g., filtering, sieving, compositing)
- Visual classification of sample using an accepted classification system
- A description of the sampling methodology used

Appendix H
Active Cell Concentration Trends

ACTIVE CELL Monitoring Data Summary NAVFAC Naval Weapons Station - Site 70 Seal Beach, CA		Tetrachloroethene	Trichloroethene	cis-1,2-Dichloroethene	trans-1,2-Dichloroethene	Vinyl Chloride	Ethene	Ethane	Methane	Alkalinity	Nitrate	Sulfate	Chloride	Chemical Oxygen Demand	Dehalococcoides - 16S rRNA	Dehalococcoides - tceA	Dehalococcoides - bvcA	Dehalococcoides - vcrA	pH	ORP	DO	Conductivity	Ferrous Iron	Comments
Units:		µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	mg/L	mg/L	mg/L	mg/L	mg/L	gene copies/L					mV	mg/L	µmhos/cm	mg/L	
AMW-1	4/9/2008 -PP	20 U	2100	83	25	20 U	5 U	5 U	5 U	860	0.89	8700	1400	34	ND	ND	ND	ND	7.38	115	2.87	17496	0	
	4/9/2008 - BP	17 U	1800	85	25	17 U	5 U	5 U	5 U	NS	NS	NS	NS	NS	NS	NS	NS	NS						
	5/14/08	4.7 J	2000	140	49	10 U	5 U	5 U	5 U	910	0.94	8100	1200	26	ND	NS	NS	NS	7.49	66.8	4.04	16072	0	
	5/14/2008 - K	4.6 J	1900	140	44	8.3 U	5 U	5 U	5 U	910	1.2	7900	1200	26	NS	NS	NS	NS						
	9/3/08	50 U	8800	480	22 J	50 U	5 U	5 U	5 U	680	0.57	5200	1700	28	ND	ND	ND	ND	6.18	212.6	4.19	1169	0	
	11/5/08	50 U	8100	990	29 J	50 U	5 U	5 U	5 U	660	0.5 U	5400	1800	32	ND	ND	ND	ND	6.86	134.9	1.31	12010	NM	
	1/29/09	50 U	7200	1200	30 J	50 U	5 U	5 U	5 U	670	0.5 U	6200	1900	38	2.56E+03	1.81E+03	ND	1.55E+03	6.79	-22.9	3.04	15450	0	
	2/24/09	50 U	38 J	7000	28 J	50 U	5 U	5 U	6	950	0.5 U	6200	2000	120	5.11E+05	1.54E+06	1.12E+05*	4.49E+05	6.61	-92.5	0.68	13311	2.6	
	3/31/09	50 U	120	6300	27 J	320	5 U	5 U	11	980	1 U	7300	1800	68	2.09E+08	7.55E+08	1.17E+08	4.85E+07	6.64	-183.9	0.08	16260	2.7	
	4/29/09	14 J	880	3000	22 J	1100	17	5 U	6	900	1 U	8100	1700	49	2.70E+08	8.06E+08	2.30E+08	1.60E+07	6.71	-50.7	1.49	16300	3.3	
	5/28/09	3.4 J	1400	2100	24	2000	16	5 U	8	870	1 U	8100	1700	44	4.08E+08	3.57E+08	8.70E+07	1.20E+07	6.58	-13.6	0.08	15920	0	
	6/23/09	17 U	1900	1200	25	2800	22	5 U	8	790	1 U	7800	1600	87	7.27E+07	1.30E+08	1.70E+07	1.40E+06	7.05	-110.9	1.88	15690	0	
	10/16/09	17 U	220	520	29	2000	660	5 U	7	1400	0.5 U	3700	1600	180	540000000	5.32E+08	6.50E+06	6.70E+06	5.24	-225.5	0.76	10980	>3.3	
AMW-2	4/8/2008 -PP	25 U	3400	630	17 J	25 U	5 U	5 U	5 U	780	0.5 U	7400	2700	38	ND	ND	ND	ND	6.92	442.6	1.15	18554	0	
	4/8/2008 - K	31 U	3500	630	12 J	31 U	5 U	5 U	5 U	780	0.5 U	7400	2700	42	NS	NS	NS	NS					0	
	4/9/2008 -BP	31 U	3300	630	16 J	31 U	5 U	5 U	5 U	NS	NS	NS	NS	NS	NS	NS	NS	NS					NM	
	5/14/08	11 J	10000	1400	41 J	21 J	5 U	5 U	13	790	0.25 U	5000	2100	44	ND	NS	NS	NS	6.7	-56.8	0.26	14500	0.125	
	9/3/08	11 J	6900	4000	25 J	31 U	5 U	5 U	6	670	0.25 U	2100	2000	78	ND	ND	ND	ND	5.83	-197.9	1.95	8146	3.3	
	11/5/08	5.6 J	1300	8400	21	35	5 U	5 U	6	660	0.25 U	2600	2100	47	3.36E+03	2.36E+03	4.60E+02	ND	6.55	-58.5	0.66	9340	>3.3	
	1/29/09	71 U	650	11000	26 J	250	5 U	5 U	12	1400	0.5 U	2900	2000	580	2.01E+06	6.16E+05	7.92E+04	1.59E+04	6.38	-159.5	0.56	11980	2.98	
	2/24/09	71 U	97	9500	19 J	940	5 U	5 U	14	1100	0.5 U	3400	2000	160	3.44E+08	8.72E+08	3.07E+08	2.10E+06	6.46	-214.2	1.31	9967	NM	
	3/31/09	36 U	230	5400	21 J	4300	5 U	5 U	5 U	980	0.25 U	3200	1700	61	4.05E+08	1.27E+09	4.71E+08	3.72E+06	6.55	-194.7	0.25	10710	>3.3	
	4/29/09	21 J	540	1700	27 J	6900	16	1 J	15	1000	0.5 U	3400	1900	63	3.17E+08	1.19E+09	4.60E+08	2.10E+05	6.47	-203.9	10.76	10750	3.3	
	5/28/09	20 J	210	780	27 J	7500	27	1 J	16	760	0.25 U	2300	1600	42	3.61E+09	1.81E+09	6.40E+08	4.50E+05	6.34	-108	-0.06	7985	2.97	
	6/24/09	50 U	280	440	50 U	6400	33	1 J	15	750	0.5 U	2100	1500	49	9.09E+07	9.80E+07	1.70E+07	6.80E+04	6.8	-135.2	1.35	8015	>3.3	
	6/24/2009-K	50 U	290	430	12 J	6500	34	1 J	15	740	0.5 U	2100	1500	47	1.23E+08	1.60E+08	2.70E+07	1.30E+05						
	10/16/09	25 U	390	730	29	4200	140	1 J	17	1900	0.03 J	540	1500	400	6900000	6.54E+07	3.60E+06	4.50E+05	5.85	-318.2	1.43	7178	0	
AMW-3 Zone 1	4/8/08	10 U	1200	32	10 U	10 U	5 U	5 U	20	560	0.21 J	7900	4000	60	ND	ND	ND	ND	6.95	195.7	0.78	22651	0	
	5/15/08	3.5 J	2800	440	16 J	9 J	5 U	5 U	17	580	0.21 J	7300	3600	60	ND	NS	NS	NS	7.12	105.8	0.35	21781	0	
	9/3/08	63 U	8100	1700	20 J	63 U	5 U	5 U	6	730	0.5 U	5900	2700	47	ND	ND	ND	ND	6.77	170.9	3.86	1519	0	
	11/5/08	50 U	8000	1900	30 J	50 U	5 U	5 U	9	710	0.5 U	6000	2900	57	ND	ND	ND	ND	6.85	478.3	1.31	15530	0	
	1/29/09	50 U	9100	1400	21 J	50 U	5 U	5 U	10	650	0.5 U	5200	2700	47	1.36E+04	2.79E+03	3.02E+02	3.15E+02	6.77	63.3	2.59	15310	0	
	2/24/09	50 U	6000	2300	20 J	210	5 U	5 U	11	630	0.5 U	4000	2300	42	4.40E+06	1.40E+07	4.72E+06	9.55E+04	6.76	74.3	3.25	10911	0.95	
	3/31/09	31 U	3900	3700	27 J	2400	15	5 U	12	870	0.5 U	3700	2200	40	5.19E+05	2.06E+06	5.43E+05	2.62E+04	6.44	-17.9	0.63	12540	0	
	4/29/09	31 U	1200	2700	23 J	3900	58	1 J	16	980	0.5 U	3700	2100	40	3.08E+05	1.18E+06	3.70E+05	6.00E+03	6.4	-31.8	1.58	11370	0.13	
	5/28/09	31 U	930	1500	32	7500	120	5 U	16	930	0.5 U	3300	1900	38	1.90E+06	1.26E+06	7.10E+05	4.10E+04	6.24	20.7	0.77	10140	0	
	6/24/09	63 U	580	690	30 J	7000	200	1 J	18	890	0.5 U	3100	1800	44	2.80E+05	2.60E+05	3.30E+04	4.9E+03*	6.59	53.4	0.84	9798	0	
	10/16/09	25 U	63	150	26	3900	680	0.7 J	7	1500	0.25 U	1100	1700	420	48800000	3.55E+07	2.90E+06	5.20E+06	5.22	13.4	3.5	9137	0	
AMW-3 Zone 2	11/6/08	50 U	7700	1300	23 J	50 U	5 U	5 U	8	660	0.5 U	4900	2500	40	ND	ND	ND	ND	6.83	497.4	1.63	14250	0	
	4/29/09	50 U	780	6500	24 J	1900	13	5 U	11	830	0.5 U	3200	2000	51	1.66E+08	5.12E+08	2.20E+08	1.60E+06	6.44	-14.9	2.16	9682	3.3	
	6/24/09	50 U	520	1400	23 J	5500	77	5 U	13	700	0.5 U	2500	1800	40	1.29E+08	1.20E+08	2.00E+07	1.60E+06	6.69	-31.8	1.58	9212	>3.3	
	10/16/09	3.3 J	31	57	29	1500	1500	0.9 J	9	1500	0.25 U	170	1500	540	378000000	2.98E+08	2.60E+06	6.00E+07	5.26	-111.9	2.79	7568	>3.3	
AMW-3 Zone 3	11/6/08	71 U	8900	780	18 J	71 U	5 U	5 U	13	530	0.5 U	3700	2300	38	ND	ND	ND	ND	6.78	80.6	1.39	13270	0.7	
	4/29/09	71 U	130	11000	19 J	190	5 U	1 J	18	830	0.5 U	2100	1600	59	1.82E+07	7.34E+07	2.60E+07	4.60E+05	6.38	-95.6	2.47	9428	3.3	
	6/24/09	42 U	87	2000	21 J	5300	27	2 J	22	670	0.25 U	1900	1600	44	2.07E+08	1.80E+08	3.50E+07	4.50E+05	6.68	-72.6	1.23	7396	2.28	
	10/16/09	42 U	43	65	24 J	6000	59	1 J	12	870	0.25 U	1400	1600	41	39300000	1.96E+07	2.90E+06	1.40E+05	5.19	-71.1	1.51	6537	>3.3	
AMW-3 Zone 4	4/8/08	1.3 J	96	5.2	0.9 J	2.5 U	5 U	5 U	5 U	NS	NS	NS	NS	NS	NS	NS	NS	NS	7.2	144.3	0.78	29500	NM	
AMW-4 Zone 1	4/8/08	13 U	1800	86	7.9 J	13 U	5 U	5 U	21	560	0.14 J	6300	3600	48	ND	ND	ND	ND	6.86	161.5	0.54	18849	0.17	
	5/15/08	6.6 J	7000	1500	39	24 J	5 U	5 U	8	720	1 U	4800	2500	120	ND	NS	NS	NS	6.96	-56.4	0.29	14952	0.27	
	9/3/08	50 U	8100	1600	33 J	15 J	5 U	5 U	7	720	0.5 U	5200	2600	51	ND	ND	ND	ND	6.45	22.4	36.76*	1359	3.16	
	11/6/08	71 U	8600	1300	29 J	71 U	5 U	5 U	9	710	0.5 U	5900	2800	47	2.07E+03	2.15E+03	4.00E+02	ND	6.84	-22.11	1.26	14850	3.1	
	1/29/09	6.7 J	3000	7600	26	240	5 U	5 U	10	800	0.5 U	4300	2500	55	7.70E+05	1.98E+05	2.50E+04	4.98E+04	6.75	-63.8	2.03	14560	2.18	
	2/24/09	50 U	310	6700	34 J	2900	15	5 U	22	970	0.5 U	3500	2300	85	4.46E+08	1.18E+09	3.72E+08	4.23E+07	6.35	-90.6	1.25	11132	2.6	
	3/31/09	50 U	180	6500	32 J	3800	49	5 U	12	950	0.25 U	2500	1800	57	5.13E+08	1.68E+09	5.21E+08	2.41E+07	6.31	-113.3	0.96	9975	2.2	
	4/29/09	36 U	250	4100	33 J	5400	59	1 J	14	860	0.5 U	2300	1800	49	2.41E+08	7.80E+08	2.90E+08	9.10E+05	6.26	-134.6	3.66	8503	3.3	
	5/28/09	36 U	220	900	30 J	9200	110	5 U	19	830	0.18 J	2100	1700	44	1.37E+08	6.86E+07	4.30E+07	3.00E+05	6.17	-95.9	0.15	7791	>3.3	
	6/24/09	63 U	150	380	26 J	7000	110	1 J	16	720	0.5 U	2200	1700	49	7.48E+07	6.60E+07	1.10E+07	6.30E+05	6.65	-98.4	1.16	7784	3.07	
	10/16/09	25 U	63	150	26	3900	680	0.7 J	7	1500	0.25 U	1100	1700	420	48800000	3.55E+07	2.90E+06	5.20E+06	5.41	-256.1	1.38	6.698	>3.3	
AMW-4 Zone 2	4/8/08	5 U	610	8.8	2.4 J	5 U	5 U	5 U	41	630	0.13 J	6900	3200	44	ND	ND	ND	ND	6.83	156.5	0.67	18399	0	
	11/6/08	71 U	10000	1700	71 U	71 U	5 U	5 U	10	580	0.25 U	3300	2200	36	ND	ND	ND	ND	6.69	-51.1	1.08	10440	1.42	
	4/29/09	71 U	81	5500	26 J	8100	12	5 U	12	790	0.25 U	1800	1600	53	1.43E+09	5.69E+09	2.00E+09	1.40E+06	6.2	-88.9	2.61	7541	3.3	
	6/24/09	71 U	44 J	62 J	71 U	7600	65	1 J	14	650	0.25 U	1700	1600	44	1.91E+08	1.60E+08	2.80E+07	3.60E+05	6.61	-66.5	1.08	6755	2.94	
	10/16/09																		5.43	-245.6	1.26	6.084	>3.3	

ACTIVE CELL Monitoring Data Summary NAVFAC Naval Weapons Station - Site 70 Seal Beach, CA		Tetrachloroethene	Trichloroethene	cis-1,2-Dichloroethene	trans-1,2-Dichloroethene	Vinyl Chloride	Ethene	Ethane	Methane	Alkalinity	Nitrate	Sulfate	Chloride	Chemical Oxygen Demand	Dehalococcoides - 16S rRNA	Dehalococcoides - tceA	Dehalococcoides - bvcA	Dehalococcoides - vcrA	pH	ORP	DO	Conductivity	Ferrous Iron	Comments
Units:		µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	mg/L	mg/L	mg/L	mg/L	mg/L	gene copies/L					mV	mg/L	µmhos/cm	mg/L	
AMW-4 Zone 3	4/8/08	10 U	1200	49	4.1 J	10 U	5 U	5 U	19	640	0.5 U	7000	2900	38	ND	ND	ND	ND	7	93	3.3	18109	0	
	11/6/08	36 U	7900	1100	24 J	36 U	5 U	5 U	5 U	600	0.25 U	3300	2100	38	ND	ND	ND	ND	6.78	-2.1	1.47	10310	0.37	
	4/29/09	50 U	4200	7400	26 J	2000	5 U	5 U	6	880	0.07 J	2400	1800	40	1.08E+06	6.10E+06	2.50E+06	7.90E+02	6.26	14.5	1.5	7898	1.02	
	6/24/09	36 U	1900	3400	22 J	4600	11	5 U	8	800	0.5 U	2100	1600	40	1.39E+07	1.50E+07	2.50E+06	1.20E+04	6.77	12.4	1.86	8306	0.94	
	10/16/09	36 U	540	410	24 J	5200	47	0.4 J	5	1100	0.25 U	1300	1500	30	15000000	1.06E+07	1.30E+06	9.90E+04	5.05	-78.7	1.57	7090	0.25	
AMW-4 Zone 4	4/8/08	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	7.33	141.5	1.17	24495	NM	Well Dewatered
AMW-5 Zone 1	4/9/08	1.7 J	710	14	4.2 J	5 U	5 U	5 U	28	450	0.16 J	3600	2900	42	ND	ND	ND	ND	6.97	-82.9	0.85	13510	0.24	
	5/15/08	20 U	2900	200	11 J	20 U	5 U	5 U	19	490	1 U	4300	3200	48	1.83E+02	4.10E+01	3.80E+01	ND	7.03	-112.2	0.31	15720	0	
	9/3/08	14 J	4600	560	13 J	42 U	5 U	5 U	10	580	0.5 U	4700	3000	47	1.04E+05	2.43E+04	ND	ND	6.09	14.9	5.51	1478	0	
	11/6/08	25 U	5200	650	18 J	25 U	5 U	5 U	14	590	0.5 U	4900	3100	47	ND	ND	ND	ND	6.9	19.6	0.98	14720	0	
	1/29/09	36 U	6400	1500	19 J	36 U	5 U	5 U	11	640	0.5 U	4800	2900	51	2.26E+03	3.75E+02	2.39E+01	9.80E+01	6.83	-43.9	2.11	15340	0	
	2/24/09	36 U	5800	2800	22 J	57	5 U	5 U	17	730	0.5 U	5200	2900	49	1.30E+05	3.97E+05	1.11E+05	2.04E+03*	6.62	-93.2	1.27	13373	0	
	3/31/09	36 U	3000	4700	24 J	1200	8	5 U	14	980	0.5 U	4200	2400	36	3.16E+06	1.10E+07	3.50E+06	4.04E+04	6.42	-85.4	0.79	13140	0.06	
	4/29/09	36 U	2600	5500	29 J	3500	19	5 U	17	1000	1 U	4300	2300	44	3.63E+06	1.45E+07	5.90E+06	3.40E+03	6.41	-10.9	1.78	12130	0	
	5/28/09	36 U	1300	3100	35 J	6100	61	5	18	1000	0.5 U	3800	2100	59	3.54E+07	3.13E+07	5.50E+06	1.60E+05	6.25	10.2	0.13	10690	0	
	6/24/09	36 U	1100	1500	20 J	6000	86	5 U	19	940	0.5 U	3600	1900	83	3.96E+06	4.45E+06	7.80E+05	1.20E+04	6.7	-27.8	1.1	10620	0	
	10/16/09	36 U	940	1400	27 J	5400	160	1 J	15	870	0.5 U	3700	2000	50	1.55E+03*	ND	2.6E+01*	ND	5.21	-104.5	1.54	10230	0	
AMW-5 Zone 2	4/9/08	2.1 J	1100	21	4.2 J	8.3 U	5 U	5 U	48	630	0.18 J	7100	3100	40	ND	ND	ND	ND	6.83	15.3	0.71	18118	0	
	11/6/08	31 U	5700	5200	55	18 J	5 U	5 U	13	710	0.5 U	3800	2300	42	ND	ND	ND	ND	6.68	-20	1.23	12550	3.23	
	4/29/09	36 U	81	9000	28 J	5200	40	1 J	15	820	0.5 U	2000	1600	70	9.54E+08	3.81E+09	1.60E+09	3.10E+07	6.39	-90.1	2.01	8896	NM	
	6/24/09	50 U	91	290	50 U	6900	63	5 U	14	660	0.25 U	1900	1500	55	3.90E+08	4.90E+08	8.60E+07	6.10E+06	6.74	-49.1	1.66	7485	3.18	
	10/16/09	25 U	27	54	25 U	2600	950	0.3 J	9	1400	0.25 U	1200	1500	350	369000000	2.54E+08	1.00E+07	7.20E+06	5.42	-184.2	1.02	6912	>3.3	
AMW-5 Zone 3	4/9/08	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	7.35	73.3	2.53	18656	NM	Well Dewatered
	11/6/08	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	6.89	19.1	1.55	16080	NM	Well Dewatered
	4/29/09	36 U	1900	4200	17 J	170	5 U	5 U	3 J	NS	NS	NS	NS	NS	NS	NS	NS	NS	6.51	99.2	4	15420	NM	Well dewatered
AMW-5 Zone 4	4/9/08	1.3 U	170	7	1.3	1.3 U	5 U	5 U	5 U	NS	NS	NS	NS	NS	NS	NS	NS	NS	7.46	87.1	1.17	21518	NM	Well Dewatered
	11/6/08	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NA	NA	NA	NA	NM	Well Dewatered
	4/29/09	NS	NS	NS	NS	NS			NS			NS		NS	NS	NS	NS	NS	6.9	49.9	7.49	20180	NM	Well Dewatered
AMW-6	4/9/08	1000 U	140000	660 J	1000 U	1000 U	5 U	5 U	40	600	0.35 J	3300	2900	58	ND	ND	ND	ND	6.65	111.8	1.04	12926	0	
	5/14/08	420 U	150000	790	420 U	420 U	5 U	5 U	47	570	0.12 J	3000	2200	42	ND	NS	NS	NS	6.93	46.1	0.8	11.829	0	
	9/3/08	1300 U	190000	1300 U	1300 U	1300 U	5 U	5U	25	530	0.25 U	3200	2200	55	209	ND	ND	ND	5.98	255.1	2.51	9607	0	
	9/3/2008 - K	1300 U	190000	450 J	1300 U	1300 U	5 U	5 U	23	530	0.25 U	3200	2200	51	ND	ND	ND	ND						
	11/5/08	1000 U	120000	710 J	1000 U	1000 U	5 U	5 U	33	540	0.1 U	3300	2200	47	ND	ND	ND	ND	6.72	200.8	0.9	9811	0	
	1/29/09	1000 U	160000	1200	1000 U	1000 U	5 U	5 U	47	580	0.5 U	3300	1900	51	ND	ND	ND	ND	6.73	-35.2	1.49	10990	0	
	2/24/09	1000 U	130000	840 J	1000 U	1000 U	5 U	5	62	520	0.5 U	3700	2200	55	1.57E+04	ND	ND	ND	6.71	17.4	0.65	10332	0	
	3/31/09	500 U	77000	840	500 U	500 U	5 U	5 U	52	630	0.26 J	3700	2100	42	2.41E+03*	1.34E+04	ND	8.26E+02*	6.86	-10.7	5.09	0.042	0	
	4/29/09	500 U	70000	1100	500 U	500 U	5 U	3 J	57	630	0.56 J	4300	2400	49	ND	2.15E+02	ND	ND	6.6	78.7	0.2	12650	0	
	5/28/09	500 U	52000	1500	500 U	500 U	5 U	2 J	49	650	0.5 U	4300	2500	55	1.52E+04	7.72E+03	4.20E+03	7.20E+02	6.48	6	0.12	12250	0	
	6/24/09	420 U	53000	3600	420 U	310 J	5 J	5 U	28	720	1 U	4600	2300	51	3.86E+03*	1.8E+03*	4.1E+02*	ND	6.85	50	0.53	12990	0	
	10/16/09	200 U	30000	4900	200 U	4100	15	0.3 J	21	720	0.5 U	3800	2000	63	ND	ND	ND	ND	5.2	-33	2.29	10440	NM	
AEW (combined extraction well effluent)	4/8/08	20 J	10000	1900	44 J	48 J	5 U	8	140	560	0.14 J	1600	1800	28	448	1.84E+02	1.40E+02	ND	6.71	225.5	128.1*	8060	0	Composite of AEW 1 & 2; DO out of range
	5/14/08	100 U	30000	2000	62 J	27 J	5 U	6	92	910	0.77	1500	1700	26	272	1.10E+02	4.00E+01	ND	7.07	140.6	1.42	8119	NM	Extraction system running. Grab sample. Composite of AEW 1 & 2.
	9/3/08	20 J	9000	420	71 U	71 U	5 U	5 U	60	540	0.25 U	1800	2100	34	3.06E+04	3.40E+03	2.08E+03	ND	5.43	204.3	3.83	7913	0	Only AEW2 running.
	11/5/08	28 J	35000	1700	47 J	29 J	5 U	6	100	570	0.25 U	1500	1100	34	1.60E+04	ND	ND	ND	NA	NA	NA	NA	NM	
	11/5/2008 - K	86 J	33000	2200	200 U	200 U	5 U	6	100	560	0.1 U	1800	2200	36	1.11E+05	1.10E+05	2.00E+04	ND						
	1/27/09	200 U	22000	930	200 U	200 U	5 U	8	160	530	0.1 U	1700	1800	34	2.17E+04	2.17E+04	2.75E+03	ND	NA	NA	NA	NA	NM	
	1/27/09 - K	200 U	23000	980	200 U	200 U	5 U	6	120	550	0.1 U	1700	1700	30	2.27E+04	1.91E+04	2.32E+03	ND						
	2/24/09	200 U	21000	1100	200 U	200 U	5 U	7	120	510	0.25 U	1700	1700	30	2.36E+04	5.27E+04	2.06E+04	5.37E+02*	6.44	44.3	1.66	6806	0	
	2/24/2009 - K	200 U	27000	1500	200 U	200 U	5 U	8	120	530	0.29	1800	1700	30	2.42E+04	9.65E+04	1.76E+04	ND						
	3/31/09	200 U	22000	1000	200 U	200 U	5 U	10	140	520	0.61	1700	1500	30	2.18E+03*	6.48E+03	1.95E+03*	5.00E+01*	6.68	-27.3	4.96	7267	0.01	
	3/31/2009 - K	200 U	23000	1000	200 U	200 U	5 U	10	140	510	0.63	1800	1500	34	7.60E+02*	3.15E+03*	7.77E+02*	ND						
	4/28/09	39 J	6500	330	11 J	13 J	5 U	5 J	54	550	0.52	1800	1600	30	ND	ND	ND	ND	6.45	140.5	2.86	7136	0	
	4/28/09-K	200 U	21000	950	200 U	200 U	5 U	5	67	550	0.41	1900	1700	32	ND	ND	ND	ND						
	5/28/09	50 U	9000	730	15 J	20 J	5 U	13	150	550	0.48	1800	1600	19	1.19E+04	3.88E+03	2.70E+03	ND	6.48	24.2	3.01	6762	0	
	5/28/2009-K	100 U	17000	1500	100 U	23 J	5 U	5 J	59	560	0.63	1800	1500	23	8.23E+03	3.84E+03	3.10E+03	ND						
	6/24/09	50 U	8000	920	17 J	23 J	5 U	5	50	520	0.62	1800	1500	61	2.79E+02*	4.10E+02	5.3E+01*	ND	6.86	15.6	1.92	6646	0.25	
	6/24/09-K	170 U	16000	1900	170 U	43 J	5 U	13	130	530	0.72	1700	1400	68	ND	1.2E+02*	5.8E+01*	ND						
	10/15/09	50 U	16000	2100	35 J	510	2 J	5	72	560	0.24 J	2000	1600	35	6.82E+03	2.73E+03*	4.6E+02*	2.0E+01*	5.54	16.7	3.73	6352	0	
	10/15/2009-K	170 U	15000	2200	42 J	510	2 J	5	70	550	0.27	1700	1400	35	3.71E+03*	1.39E+03*	2.8E+02*	3.7E+01*						

Notes:
K - Duplicate sample
J - estimated value
U - nondetect (detection limit is indicated)
NA - not analyzed
ND - not detected
NS - not sampled
* - indicates that the value presented is below the reporting limit.

µmhos/cm - micromhos per centimeter
µg/L - mcrograms per liter
mg/L - milligrams per liter
mV - millivolts
ORP - oxidation reduction potential
DO - dissolved oxygen
> - greater than
NM - not measured

February 2009	TCE (ppb)	$\delta^{13}C$	cDCE	$\delta^{13}C$	VC	$\delta^{13}C$	Ethene	$\delta^{13}C$ eth	2-butanone	chloroform	chlor/DCE
SB-AEW	21000	-24.3	1100	-26.8							
SB-AMW1-25'	27000		7000	-24.6							
SB-AMW2-25'	97		9500	-22.9	940	-43.0				75	0.01
SB-AMW3-Z1	6000	-24.5	2300	-24.5	210					55	0.02
SB-AMW4-Z1	310	-17.9	6700	-36.5	2900		59				
SB-AMW5-Z1	5800	-23.7	2800	-25.0	57					100	0.04
SB-AMW6-25'	130000	-23.9		-31.7		-28.5					
SB-PIW1-25'	42		4	-27.0						120	32.43
SB-PIW2-25'	12	-26.1	3	-27.9	23				110	3	1.00
SB-PIW3-25'	2	-23.5	1	-25.4	5				160		
SB-PMW1-25'	1700	-28.0	79							74	0.94
SB-PMW2-25'	1800		43								
SB-PMW3-Z1	41000	-23.3									
SB-PMW4-Z1	41000	-23.3									
SB-PMW5-Z1	40000	-24.6									
SB-PMW6-25'	2100	-23.3	800	-19.2	54					280	0.35
SB-PMW7-25'	6500									690	
SB-PMW8-25'	1100	-20.0	4500	-25.2						30	0.01
SB-PMW9-25'	96	-22.6	6								
Average of all		-23.5		-26.4		-35.8					
AEW/AMW Ave		-22.9		-27.4		-35.8					
PIW/PMW Ave		-23.9		-24.9							

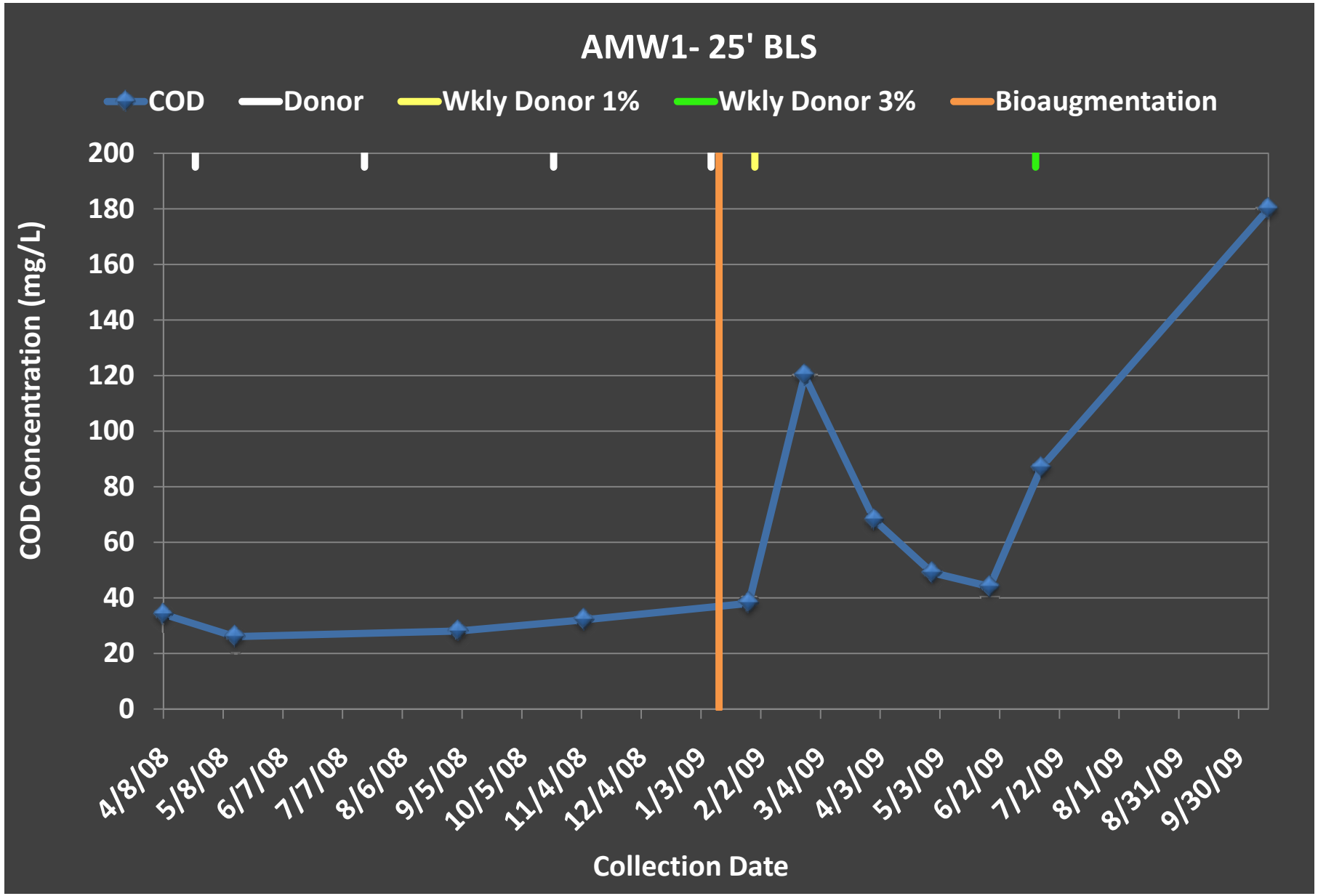
April 2009	TCE (ppb)	$\delta^{13}C$	cDCE	$\delta^{13}C$	VC	$\delta^{13}C$	Ethene	$\delta^{13}C$ eth	2-butanone	chloroform	chlor/DCE
SB-AEW	6500	-22.7	330	-24.9							
SB-AMW1-25'	880	-22.2	3000	-15.4	1100	-35.4	17				
SB-AMW2-25'	540	-9.9	1700		6900	-30.2	16				
SB-AMW3-Z1	1200	-22.5	2700	-15.9	3900	-26.2	58				
SB-AMW3-Z2	780	-22.6	6500	-13.9	1900	-40.2	13			99	0.02
SB-AMW3-Z3	130		11000		190	-47.0					
SB-AMW4-Z1	250	-16.8	4100	-9.6	5400	-32.5	14				
SB-AMW4-Z2	81		5500	-6.0	8100	-33.0	12				
SB-AMW4-Z3	4200	-21.9	7400	-19.4	2000	-37.8					
SB-AMW5-Z1	2600	-21.5	5500	-19.3	3500	-31.8	19			72	0.01
SB-AMW5-Z2	81		9000	-11.7	5200	-40.0	40				
SB-AMW5-Z3	1900	-21.5	4200	-21.8	170	-39.9				77	0.02
SB-AMW6-25'	70000	-22.9	1100	-25.1						120	0.11
SB-PIW1-25'	26		23		4			-17.2		11	0.48
SB-PIW2-25'	44	-23.1			6				180		
SB-PIW3-25'			1		6	-28.0			170		
SB-PMW1-25'	1400	-28.3	65							58	0.89
SB-PMW2-25'	280	-21.7	7							140	21.54
SB-PMW3-Z1	45000	-21.9	260							48	0.18
SB-PMW4-Z1	42000	-22.0	520							220	0.42
SB-PMW4-Z3	3400	-23.4	41							5600	136.59
SB-PMW4-Z4	7900	-23.5	57							3300	57.89
SB-PMW5-Z1	44000	-24.1								130	
SB-PMW5-Z2	7100	-24.0	56							2900	51.79
SB-PMW5-Z3	6900	-23.5	67							3800	56.72
SB-PMW6-25'	740	-17.9	360		410	-22.4	310	-27.5	42	230	0.64
SB-PMW7-25'	5800	-22.0	1700	-23.8					260	570	0.34
SB-PMW8-25'	1500	-15.5	470	-9.5	420	-14.4	330	-29.7		56	0.12
SB-PMW9-25'	110	-22.0	270	-22.8	11.0	-15.9					
Average of all		-21.6		-17.1		-31.6					
AEW/AMW Ave		-20.5		-16.6		-35.8					
PIW/PMW Ave		-22.4		-18.7		-20.2		-24.8			

June 2009	TCE (ppb)	$\delta^{13}C$	cDCE	$\delta^{13}C$	VC	$\delta^{13}C$	Ethene	$\delta^{13}C$ eth	2-butanone	chloroform	chlor/DCE
SB-AEW	8000	-24.4	920	-25.6		-37.2					
SB-AEW K	16000	-23.9	1900	-23.0							
SB-AMW1-25'	1900	-23.2	1200	-14.5	2800	-27.8	22				
SB-AMW2-25'	280	-5.2	440	6.8	6400	-26.8	33				
SB-AMW2-25' K	290	-4.3	430	6.6	6500	-26.1	34				
SB-AMW3-Z1	580	-21.9	690	-14.7	7000	-22.9	200				
SB-AMW3-Z2	520	-20.0	1400	-11.7	5500	-26.4	77				
SB-AMW3-Z3	87	-18.6	2000	-8.2	5300	-26.9	27				
SB-AMW4-Z1	150	-18.2	380	-4.8	7000	-26.9	110				
SB-AMW4-Z2					7600	-26.3	65				
SB-AMW4-Z3	1900	-22.2	3400	-16.4	4600	-27.4	11				
SB-AMW5-Z1	1100	-22.3	1500	-15.5	6000	-25.2	86				
SB-AMW5-Z2	91	-8.6	290	4.0	6900	-27.0	63				
SB-AMW6-25'	53000	-23.5	3600	-19.8	310	-27.3					
SB-PIW1-25'	13		9		19	-19.3		-12.6			
SB-PIW2-25'	17		3		8						
SB-PIW3-25'	54		2		4						
SB-PMW1-25'	1400	-28.0	69	-30.5			6				
SB-PMW2-25'	4400	-23.4									
SB-PMW3-Z1	47000	-24.3	190		310						
SB-PMW3-Z2	1400	-24.1	11								
SB-PMW4-Z1	30000	-23.3	4500	-25.2							
SB-PMW4-Z3	2000	-24.2	22								
SB-PMW4-Z4	6700	-24.3	59								
SB-PMW5-Z1	39000	-24.6	380		310						
SB-PMW5-Z2	4600	-23.9	69								
SB-PMW5-Z3	5600	-24.6	53								
SB-PMW6-25'	790	-16.2	460	-20.5	120	-18.5	190	-21.0			
SB-PMW6-25' K	910	-16.9	490	-20.3	130	-20.6	170	-21.7			
SB-PMW7-25'	190	-8.7	96	1.3	590	-18.3	28	-34.1			
SB-PMW8-25'	710	-12.6	180	-7.3	250	-8.8	350	-26.5			
SB-PMW9-25'	19	-18.8	19		37	-4.2	110	-23.4			
Average of all		-19.8		-12.6		-23.4		-23.2			
AEW/AMW Ave		-18.2		-10.5		-27.2					
PIW/PMW Ave		-21.2		-17.1		-15.0		-23.2			

October 2009	TCE (ppb)	$\delta^{13}C$	cDCE	$\delta^{13}C$	VC	$\delta^{13}C$	Ethene	$\delta^{13}C$ eth	2-butanone	chloroform	chlor/DCE
SB-AEW		-24.2		-19.8		-30.0					
SB-AMW1-25'		-20.6		-18.2		-19.6		-44.2			
SB-AMW2-25'		-6.9		-21.2		-24.5					
SB-AMW3-Z1						-21.4					
SB-AMW3-Z2											
SB-AMW3-Z3						-23.6		-28.7			
SB-AMW4-Z1						-20.5		-40.4			
SB-AMW4-Z2						-20.3					
SB-AMW4-Z3						-22.1					
SB-AMW5-Z1		-23.4		-18.5		-23.8		-48.7			
SB-AMW5-Z2											
SB-AMW5-Z3											
SB-AMW6-25'		-23.9		-17.1		-27.5					
SB-PIW1-25'		-22.9		-21.8							
SB-PIW2-25'								-42.7			
SB-PIW3-25'								-45.8			
SB-PIW3-25' K								-53.6			
SB-PMW1-25'		-28.2									
SB-PMW2-25'		-23.5									
SB-PMW3-Z1		-24.4									
SB-PMW3-Z2		-23.2									
SB-PMW3-Z3		-24.4									
SB-PMW4-Z1		-23.3		-22.8							
SB-PMW4-Z3		-24.3									
SB-PMW4-Z4		-24.7									
SB-PMW5-Z1		-23.3		-22.2		-43.3					
SB-PMW5-Z1 K		-23.5		-23.1		-42.4					
SB-PMW5-Z2		-23.1									
SB-PMW5-Z3		-23.2									
SB-PMW6-25'		-17.7		-18.4		-19.8		-43.3			
SB-PMW7-25'											
SB-PMW8-25'		-19.2						-36.2			
SB-PMW9-25'								-40.3			
Average of all		-22.4		-20.3		-26.1		-42.4			
AEW/AMW Ave		-19.8		-19.0		-23.3		-40.5			
PIW/PMW Ave		-23.3		-21.7		-35.2		-43.7			

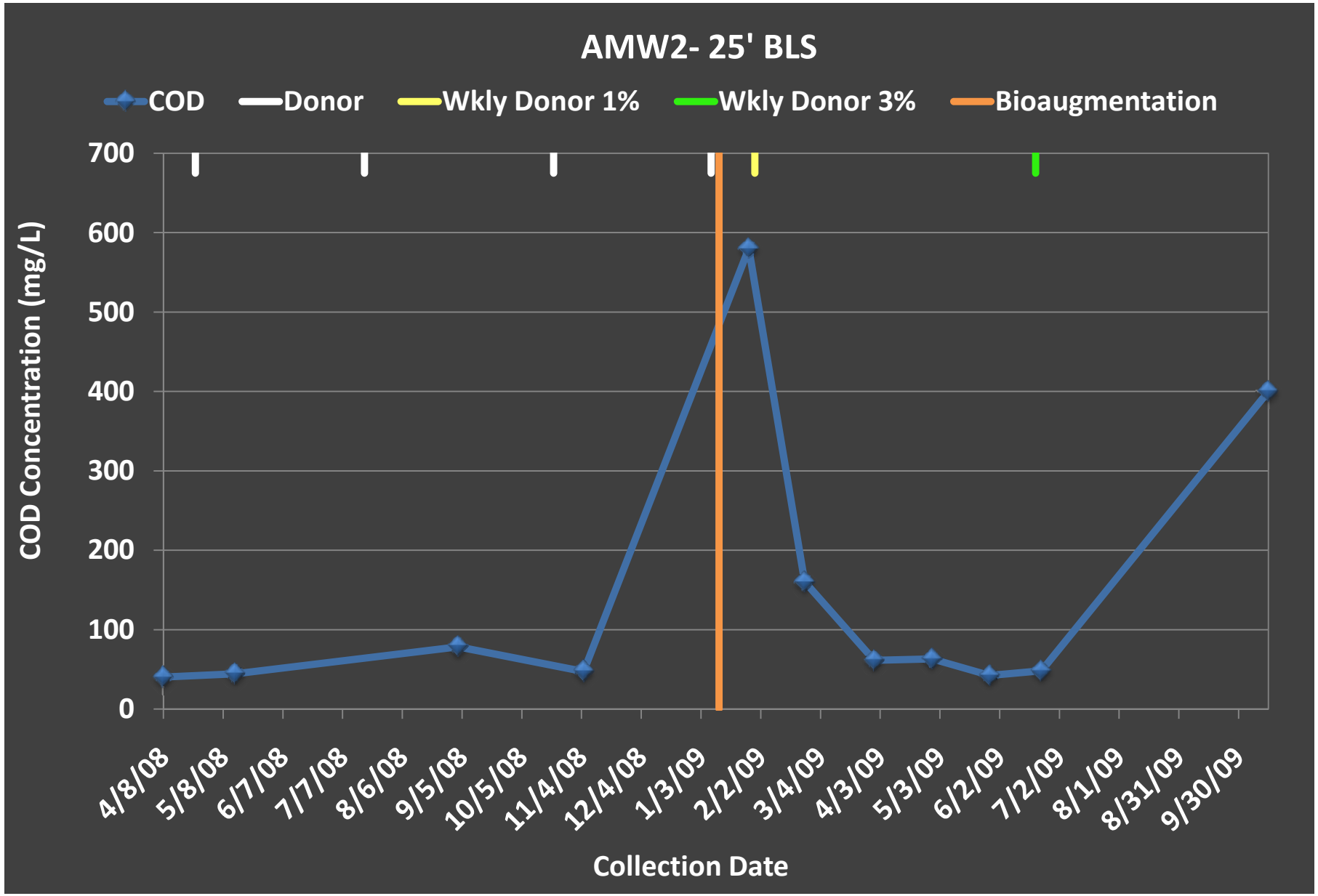
COD

Seal Beach
Groundwater Bioaugmentation



Recirculation system was shut off between 9/2/2008 and 1/6/2009.

Seal Beach
Groundwater Bioaugmentation



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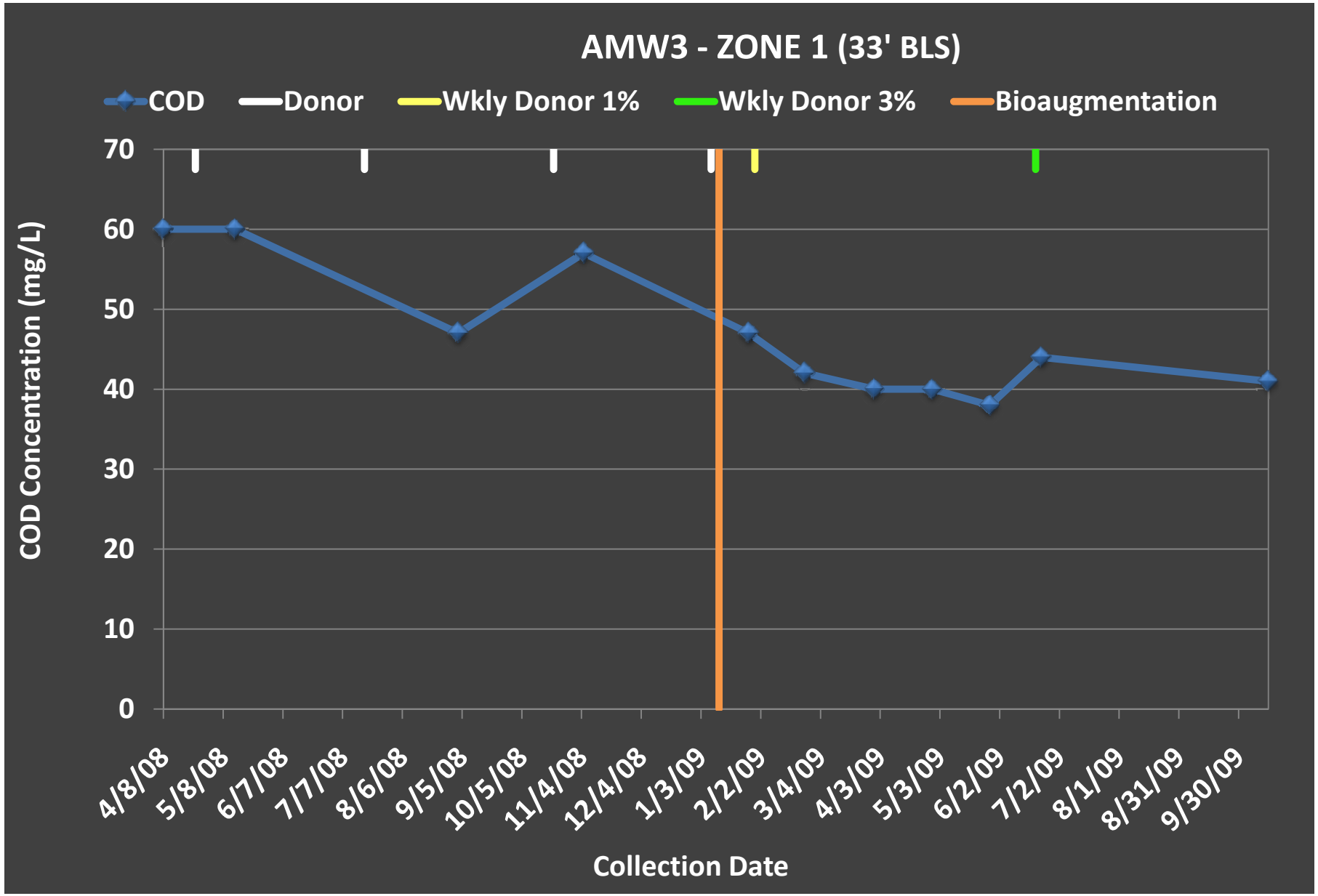
Seal Beach
Groundwater Bioaugmentation



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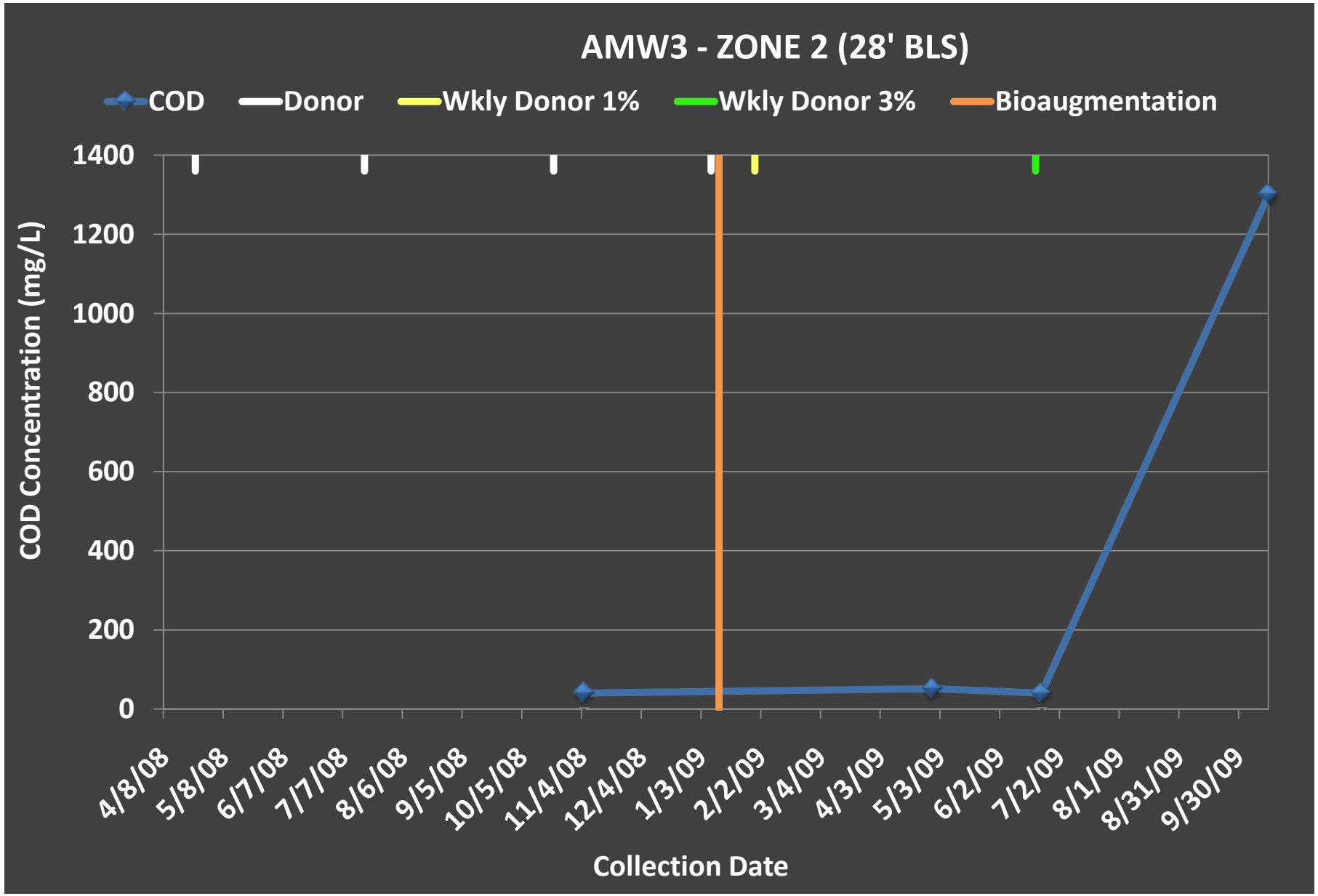
Seal Beach
Groundwater Bioaugmentation



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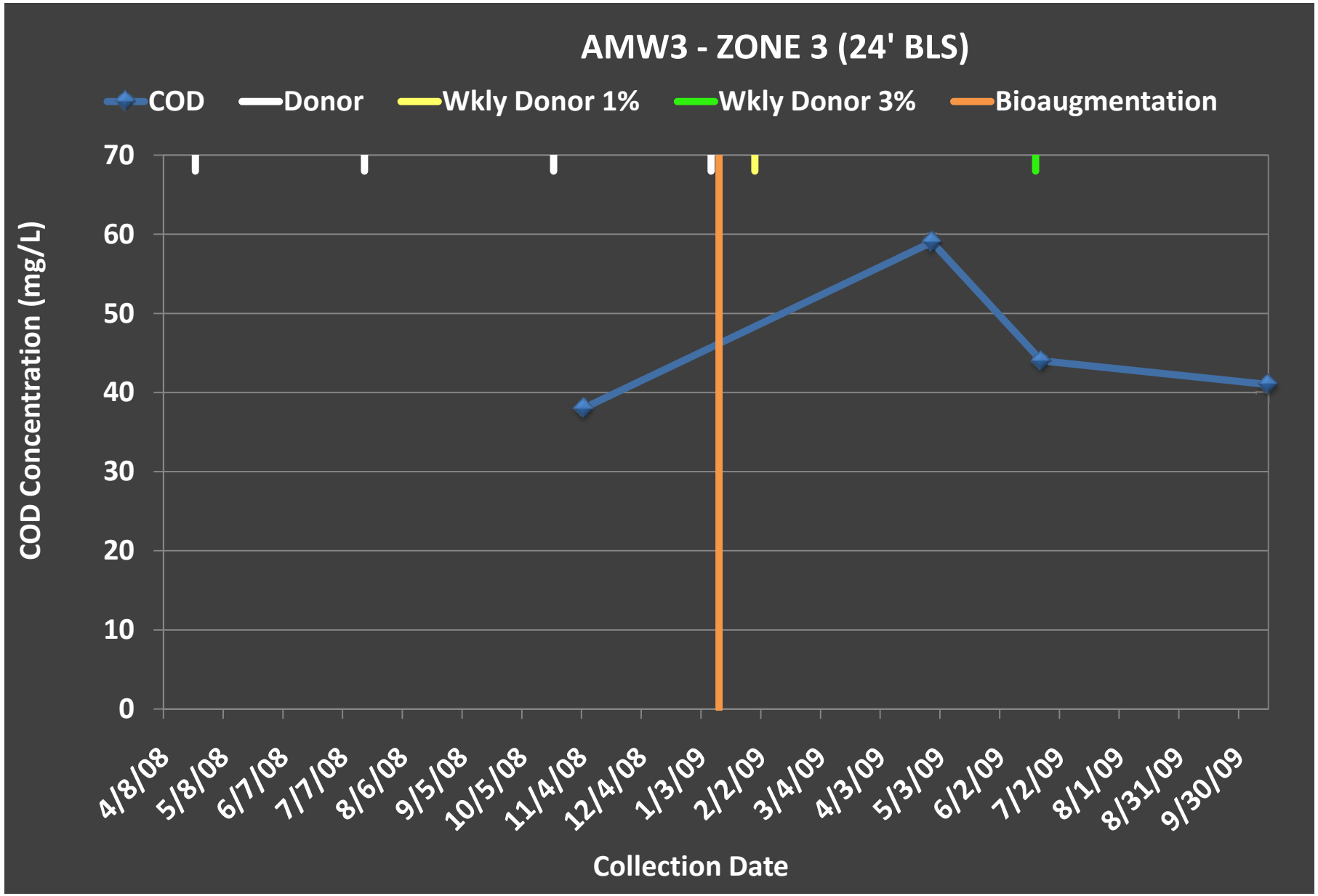
Seal Beach
Groundwater Bioaugmentation



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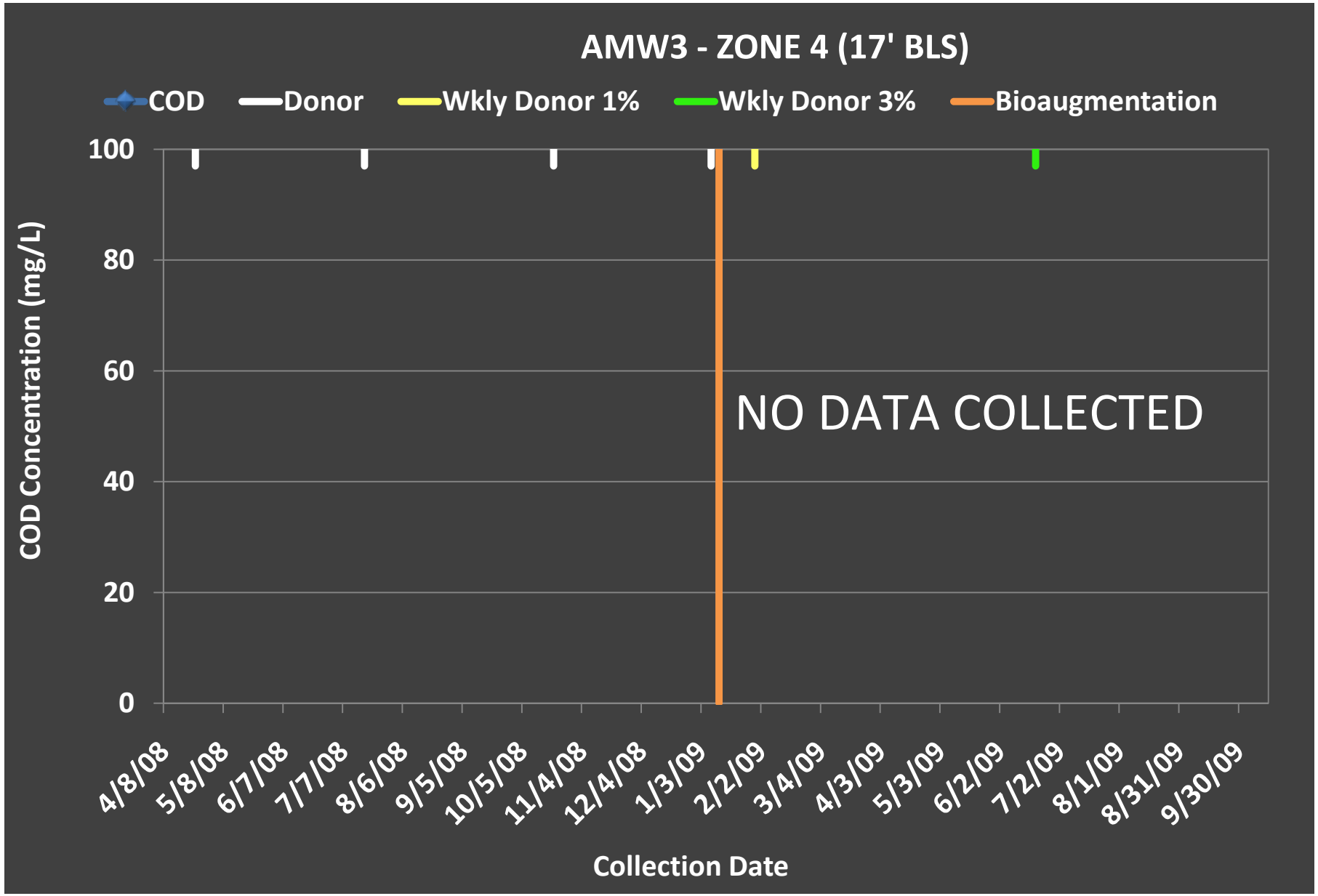
Seal Beach
Groundwater Bioaugmentation



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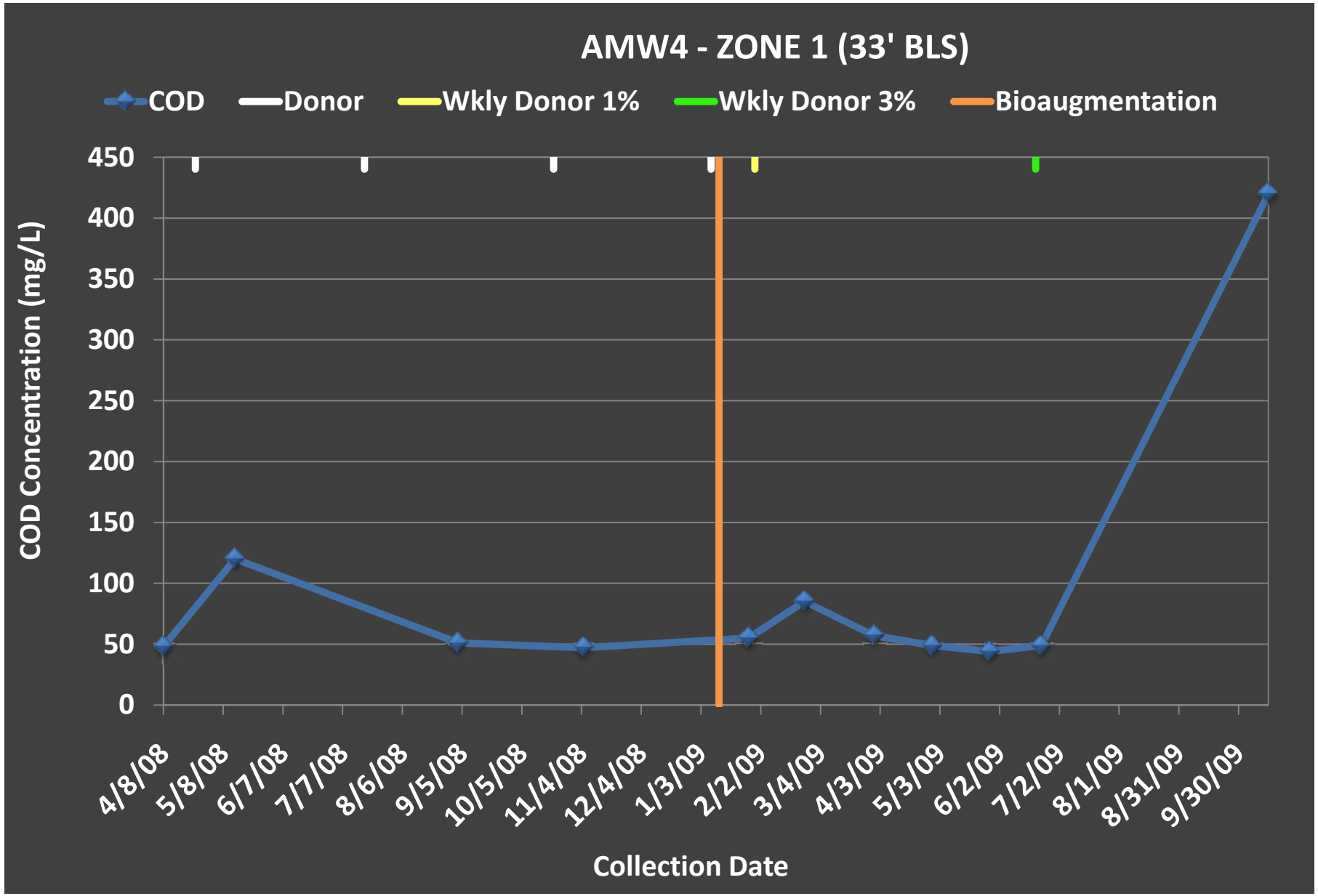
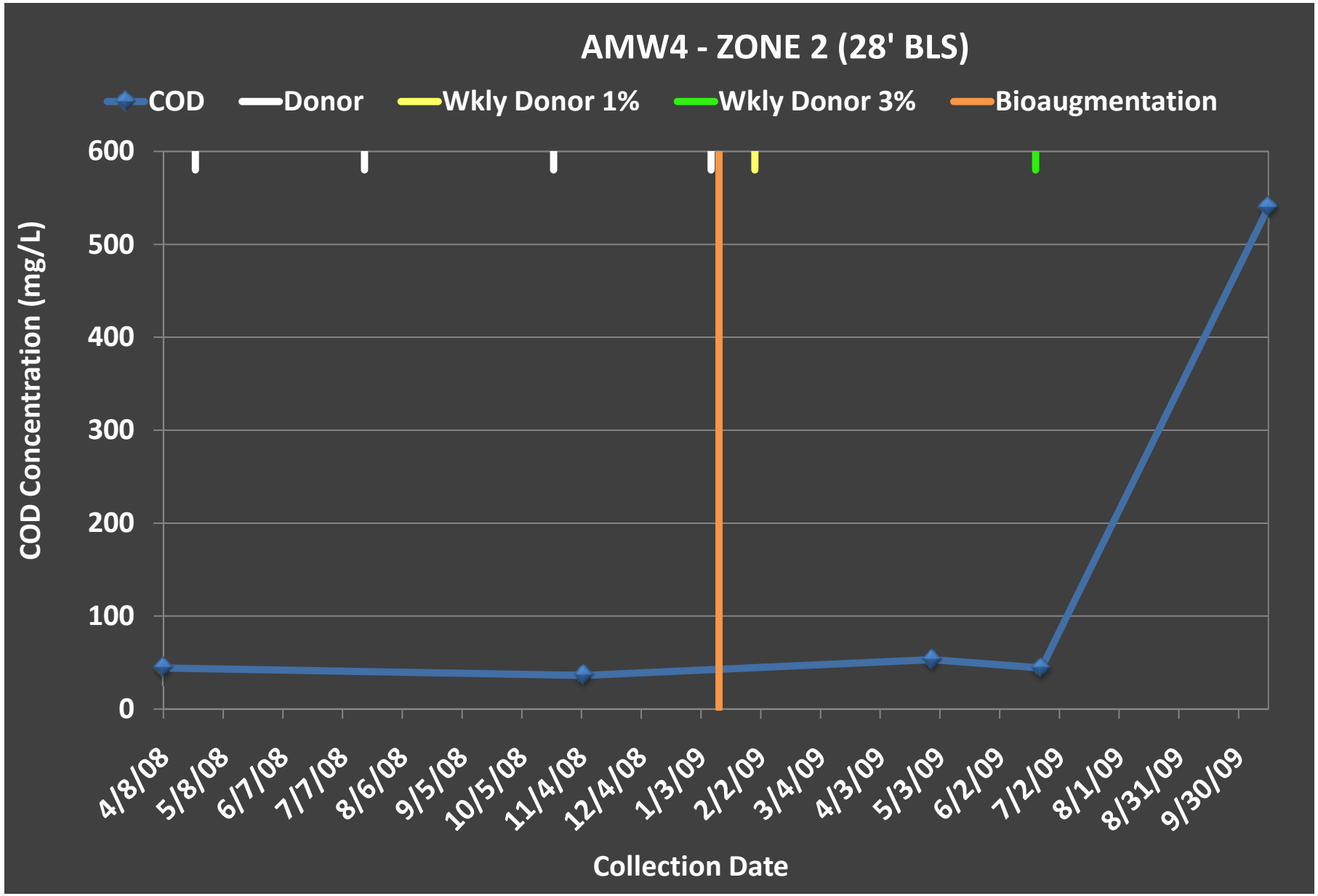
Seal Beach
Groundwater Bioaugmentation



Recirculation system was shut off between 9/2/2008 and 1/6/2009.

AMW4 Z1, COD__Act_Seal Beach_Oct 2009.xlsx

Seal Beach
Groundwater Bioaugmentation



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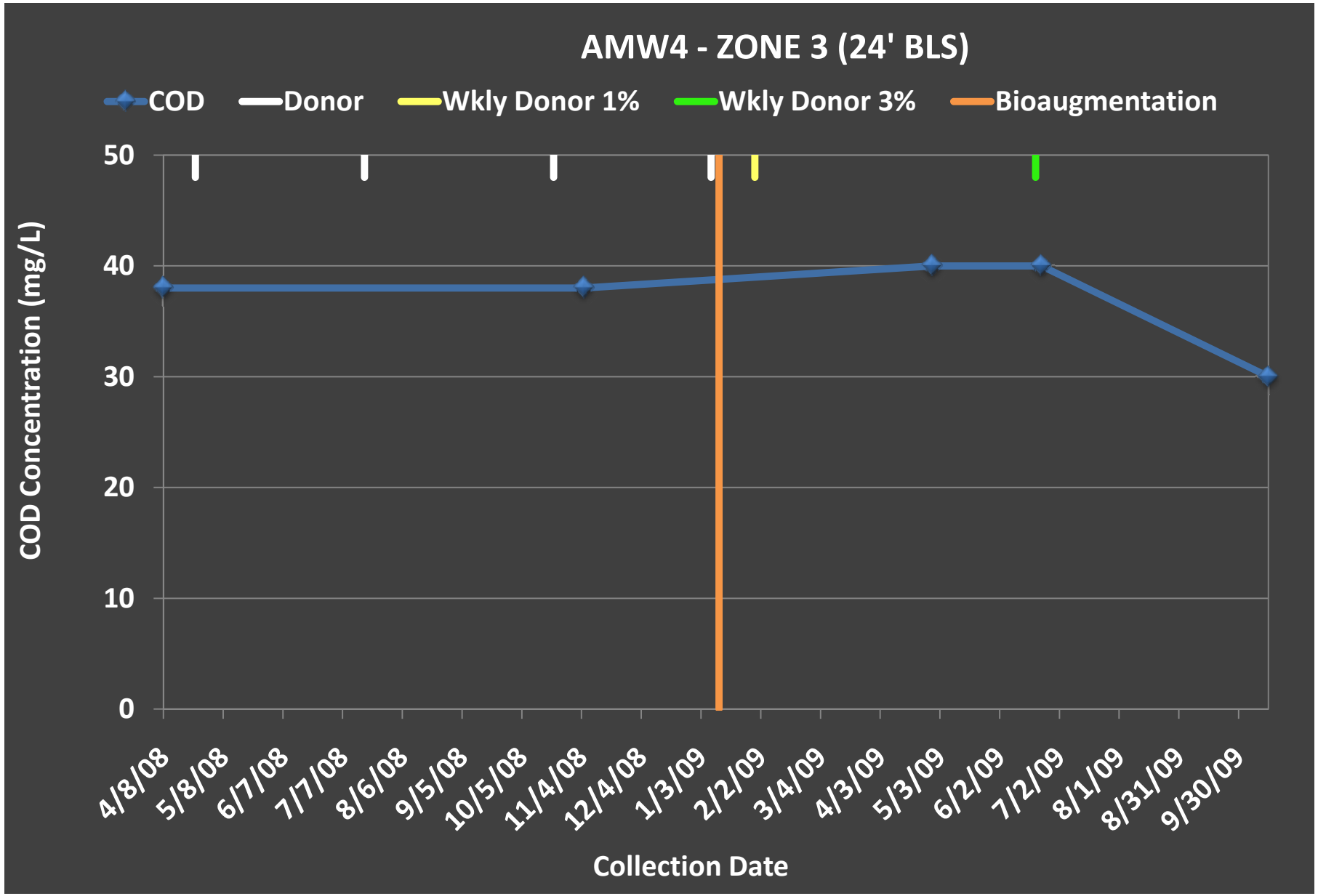
Seal Beach
Groundwater Bioaugmentation



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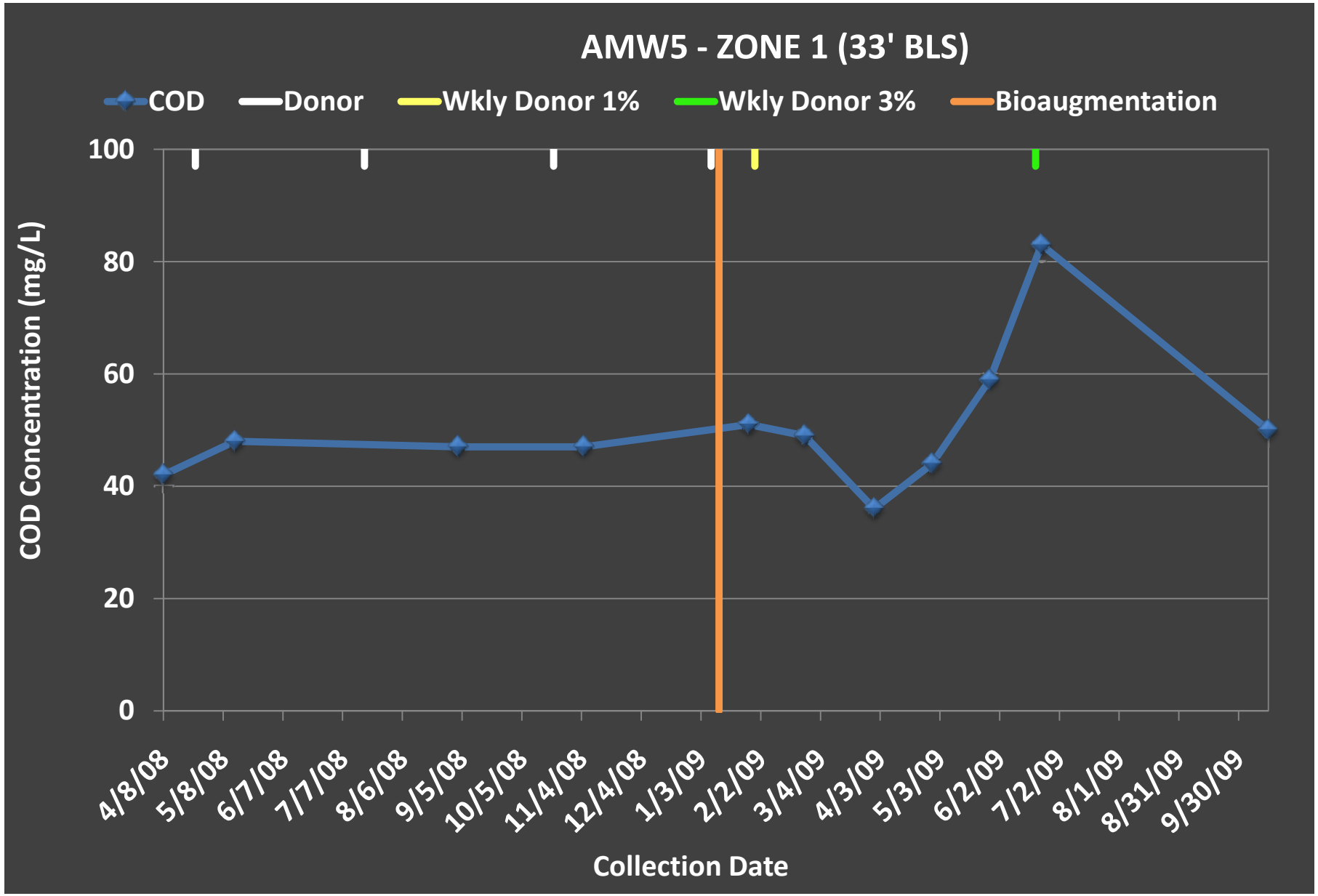
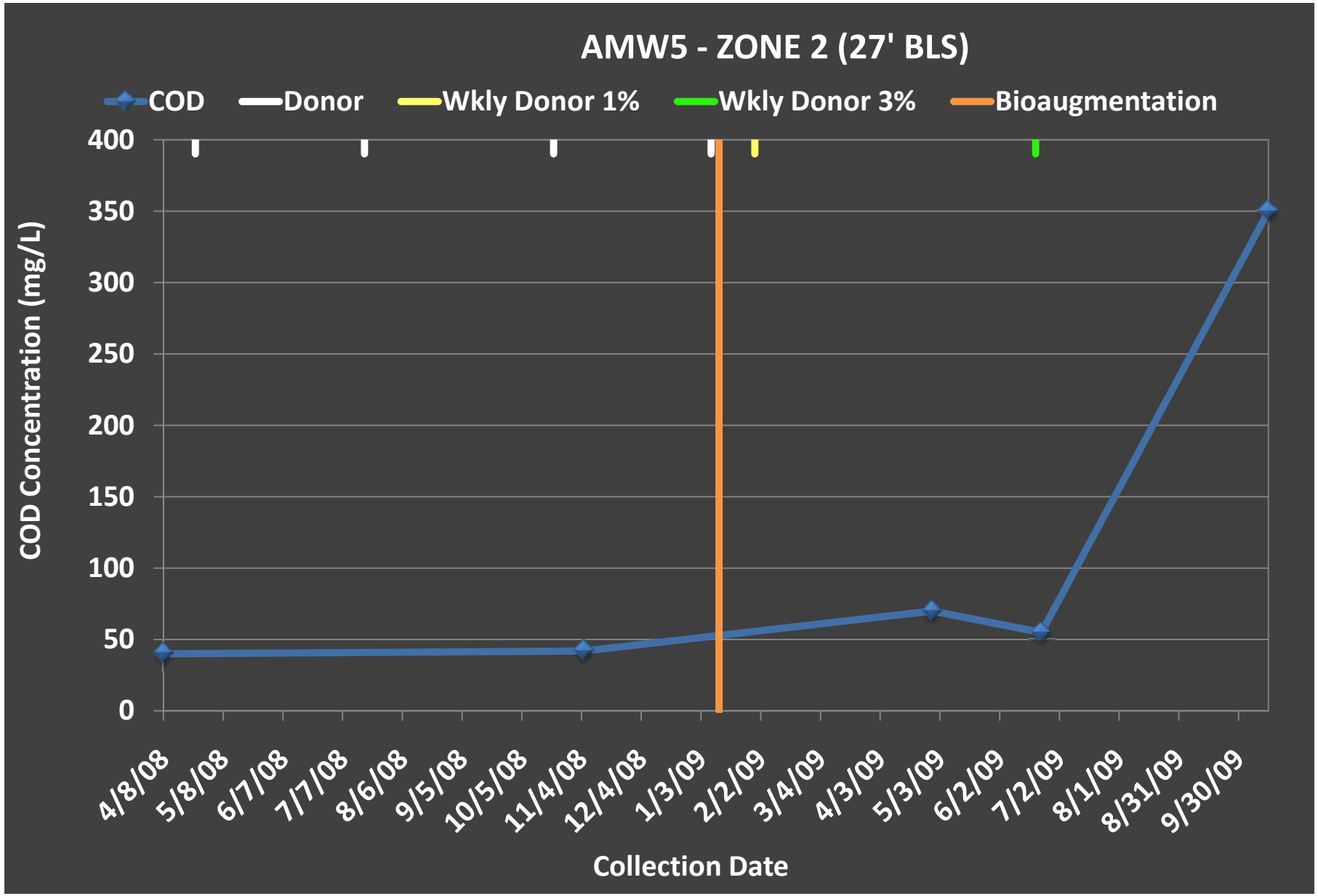
Seal Beach
Groundwater Bioaugmentation



Recirculation system was shut off between 9/2/2008 and 1/6/2009.

Seal Beach
Groundwater Bioaugmentation



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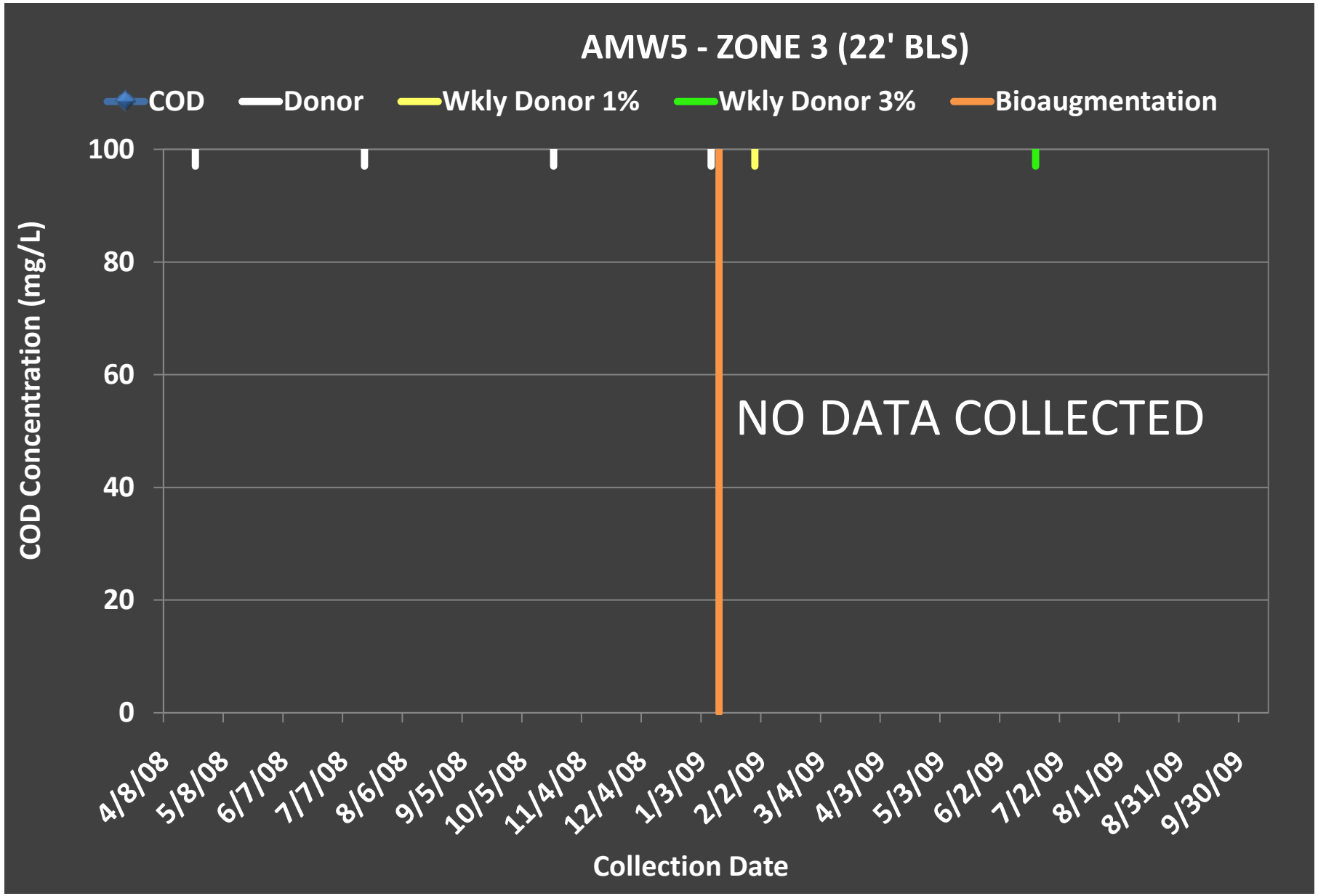
Seal Beach
Groundwater Bioaugmentation



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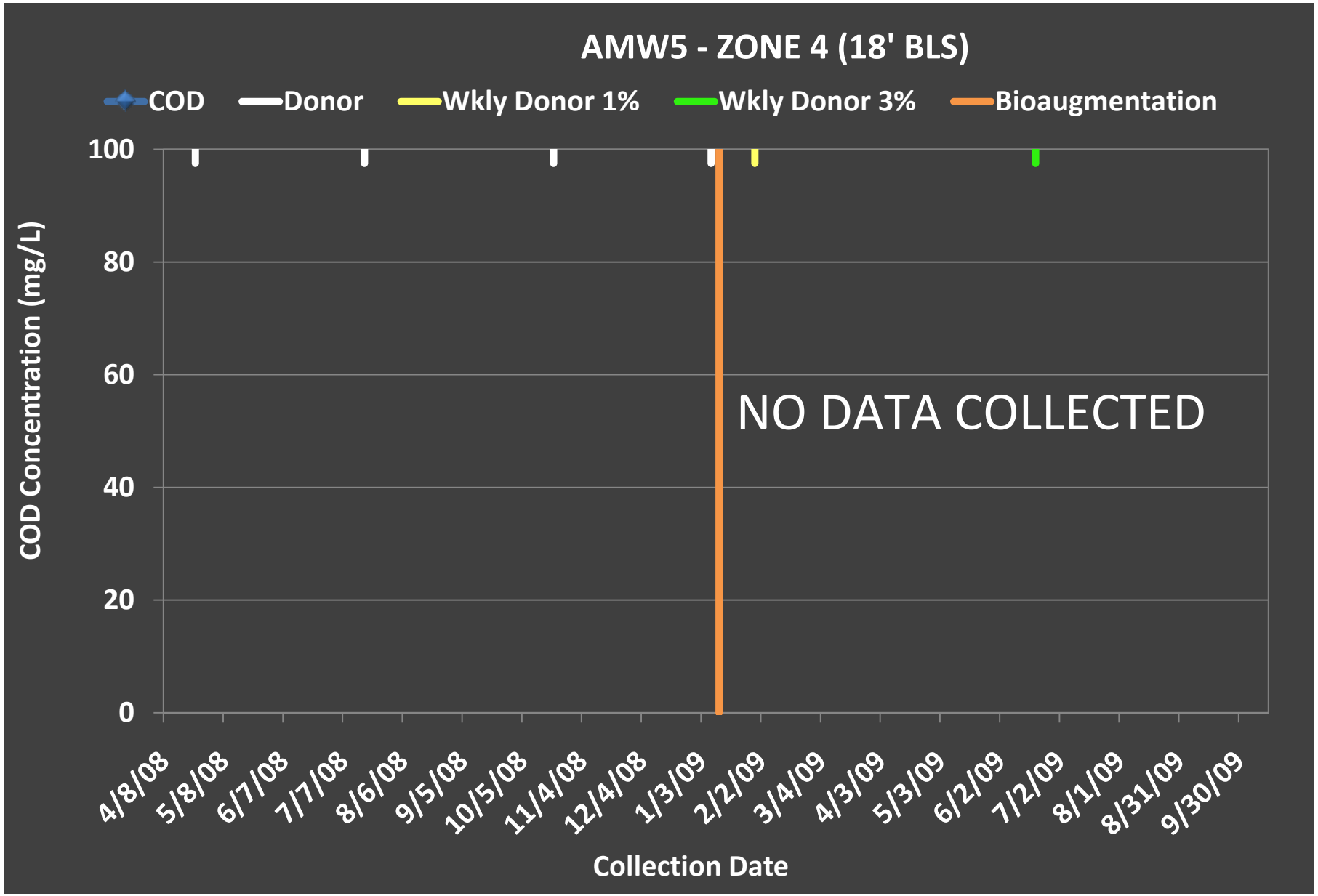
Seal Beach
Groundwater Bioaugmentation



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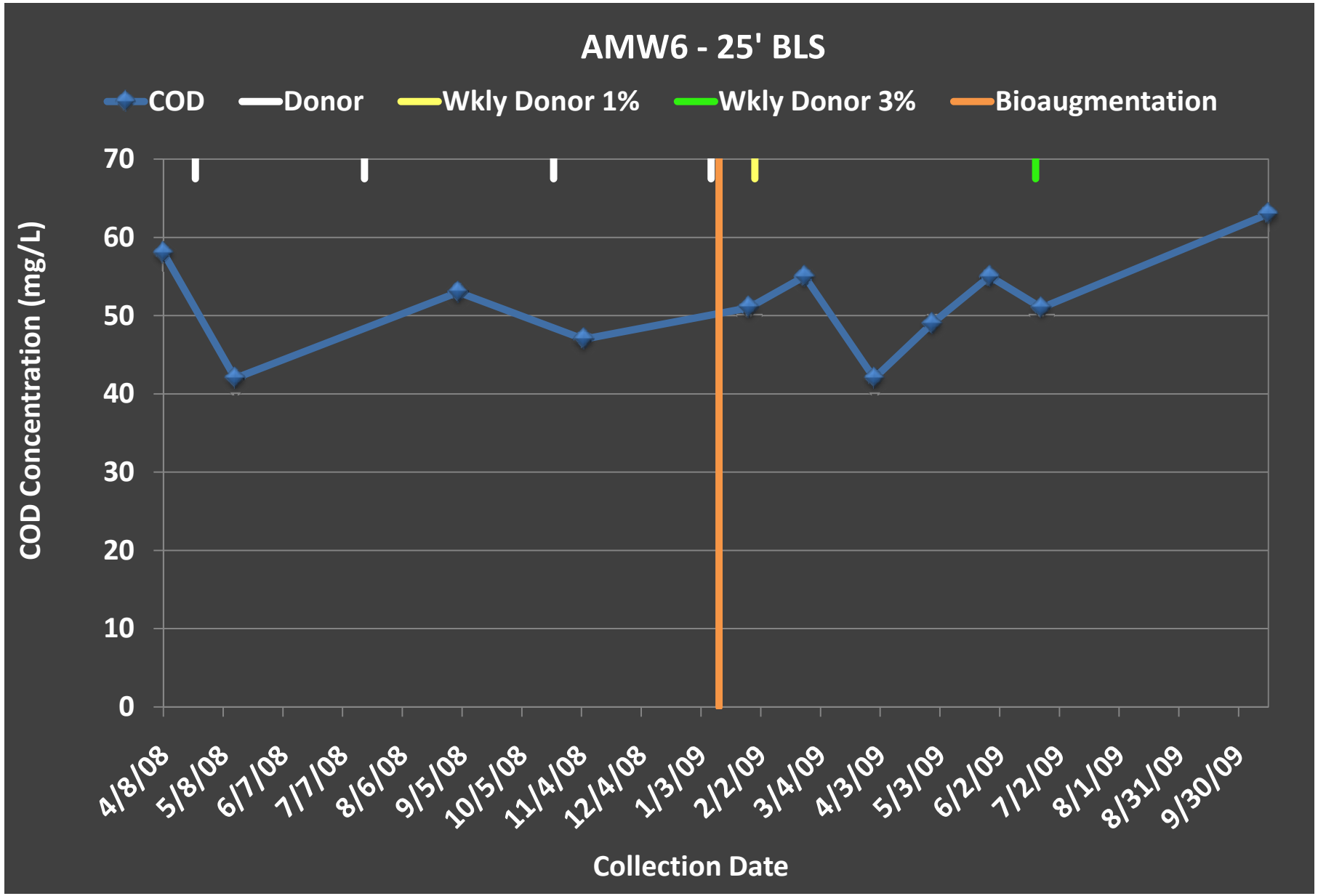
Seal Beach
Groundwater Bioaugmentation



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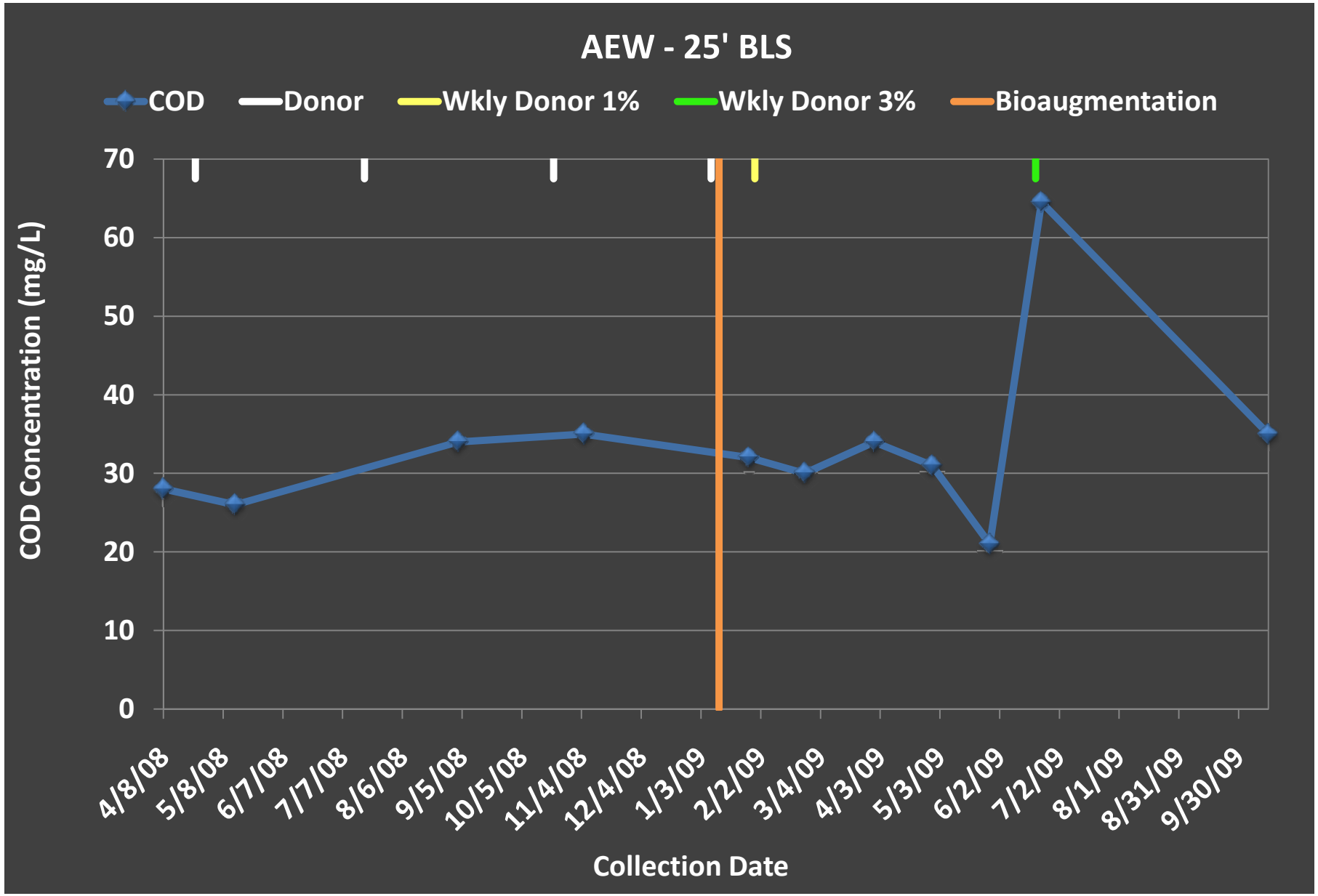
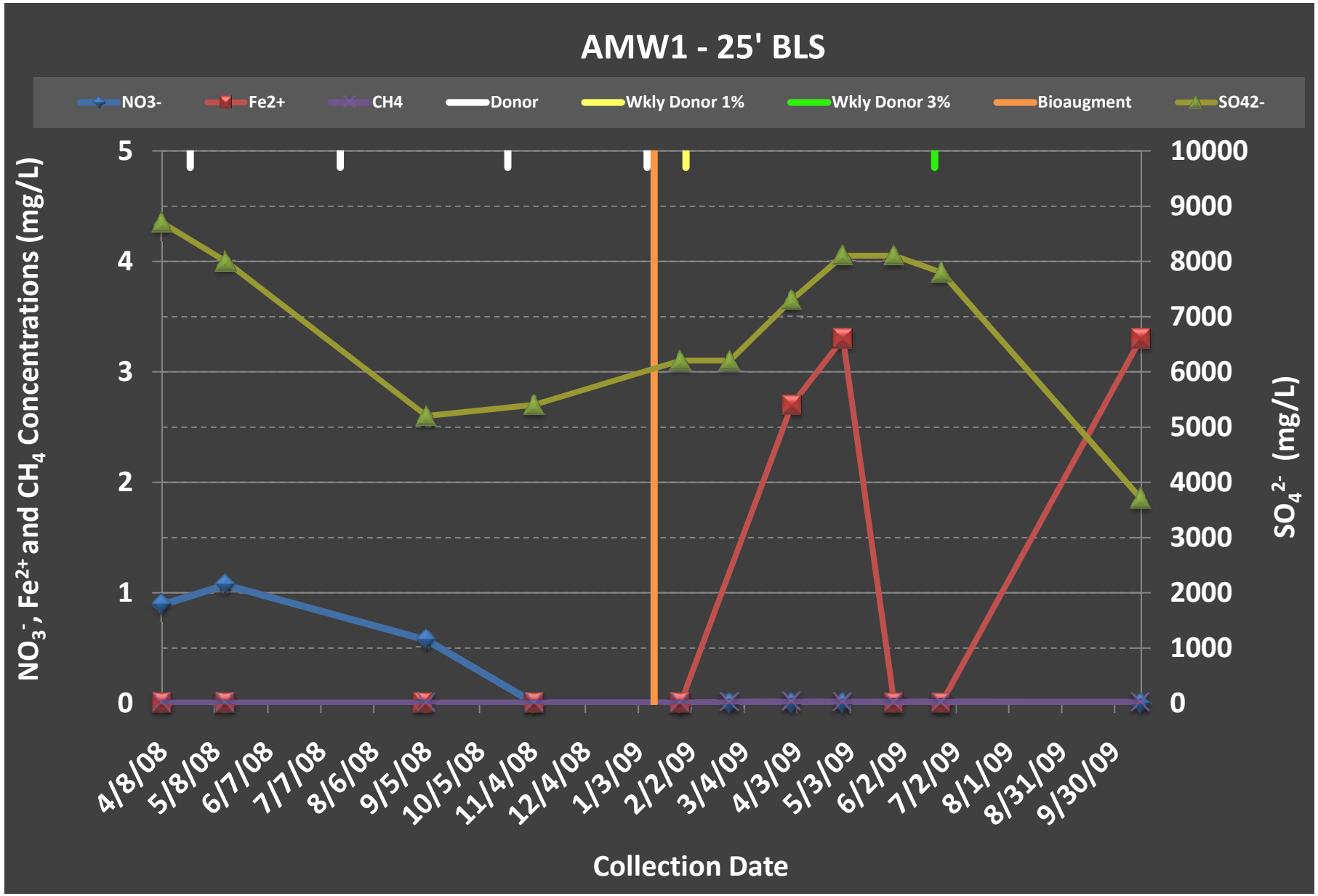
Seal Beach
Groundwater Bioaugmentation



Recirculation system was shut off between 9/2/2008 and 1/6/2009.

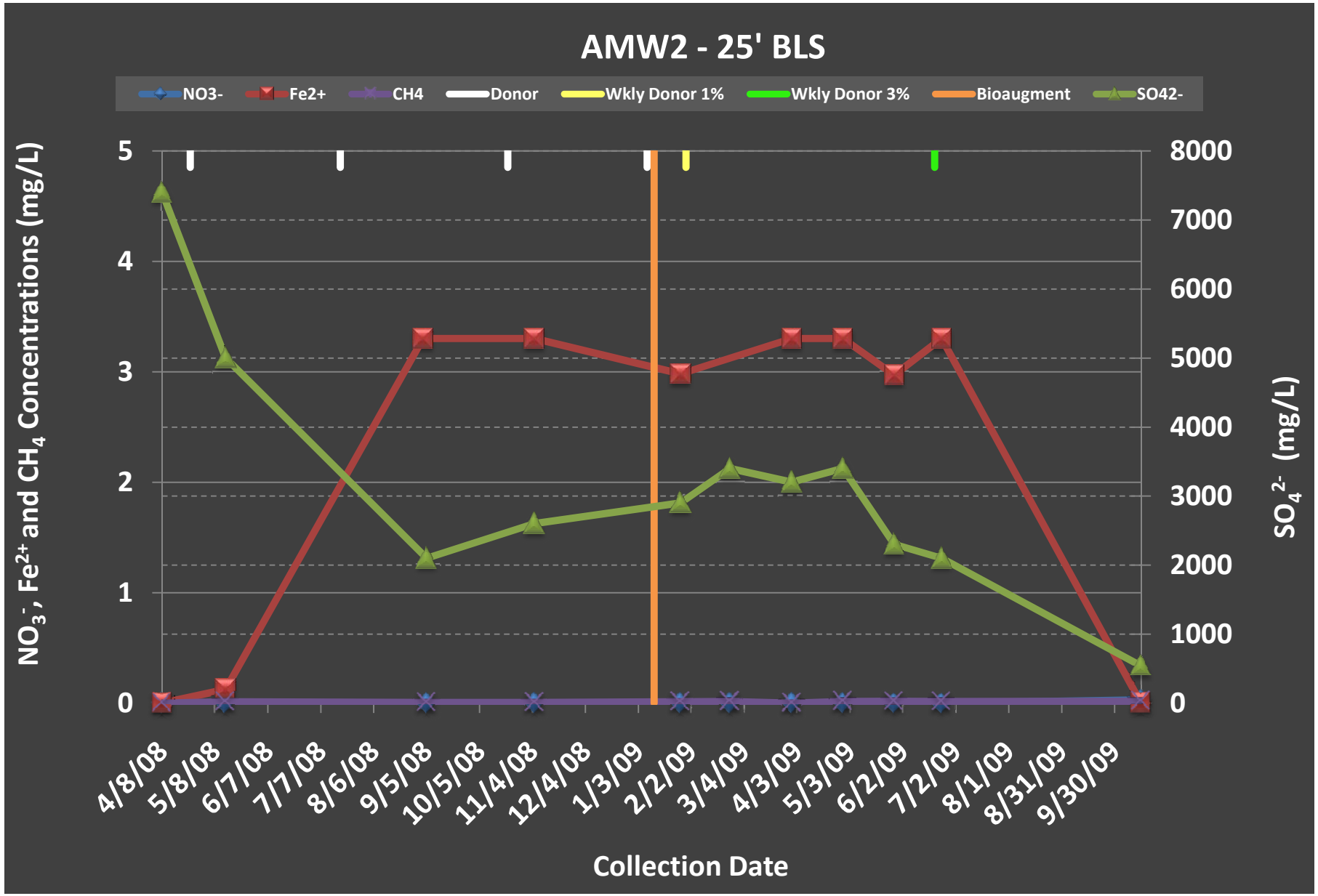
Electron Acceptors

Seal Beach
Groundwater Bioaugmentation



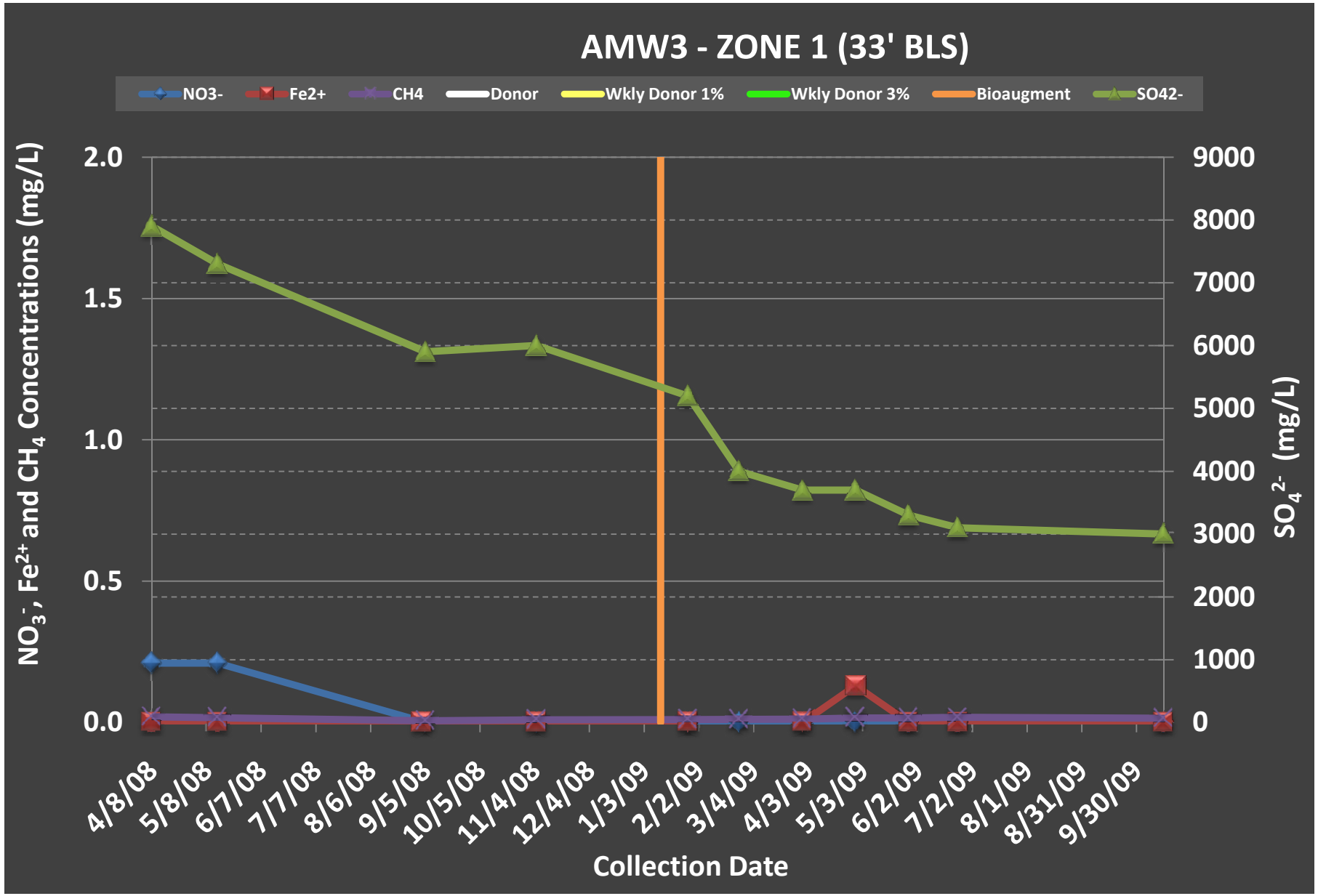
Recirculation system was shut off between 9/2/2008 and 1/6/2009.

Seal Beach
Groundwater Bioaugmentation



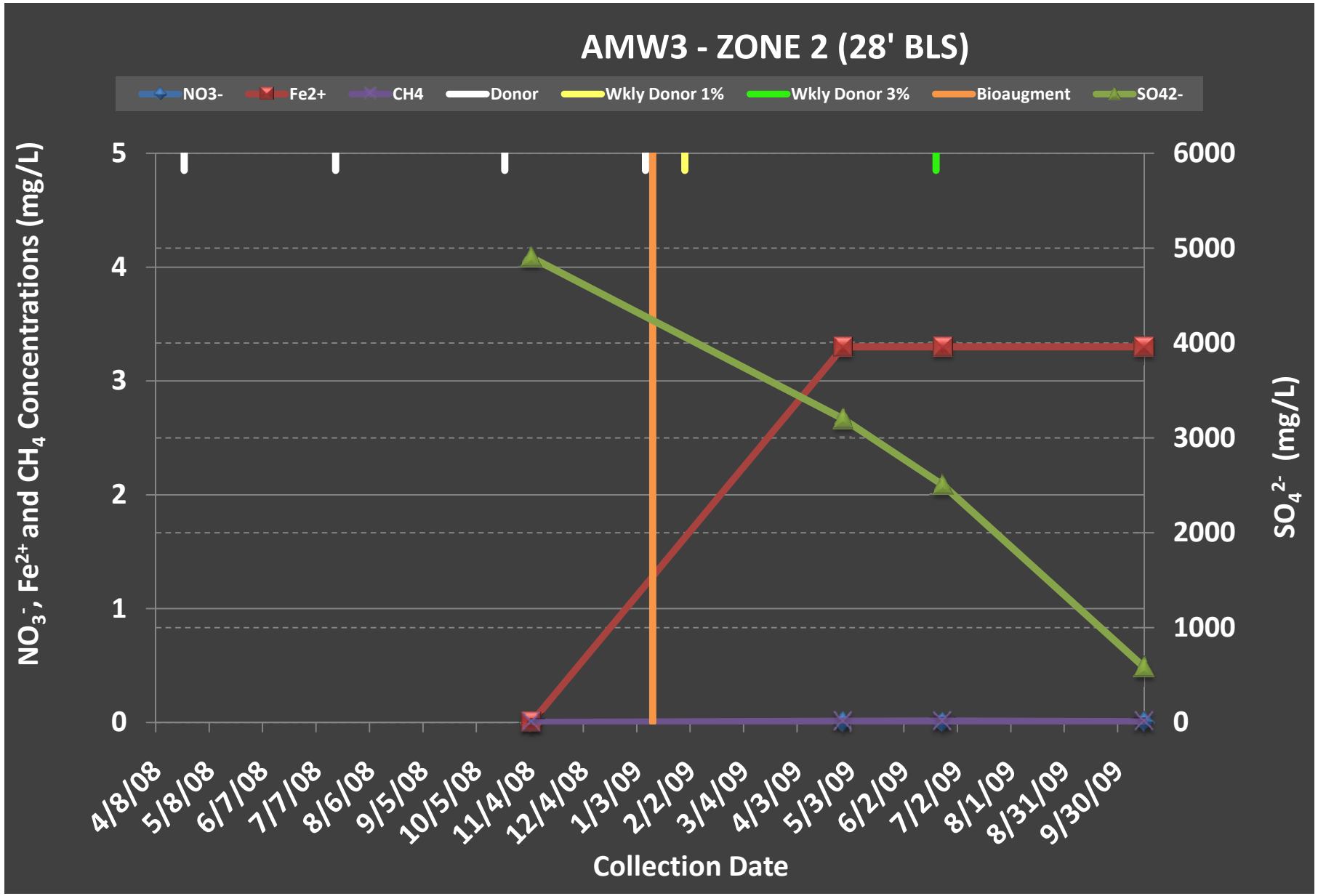
Recirculation system was shut off between 9/2/2008 and 1/6/2009.

Seal Beach
Groundwater Bioaugmentation



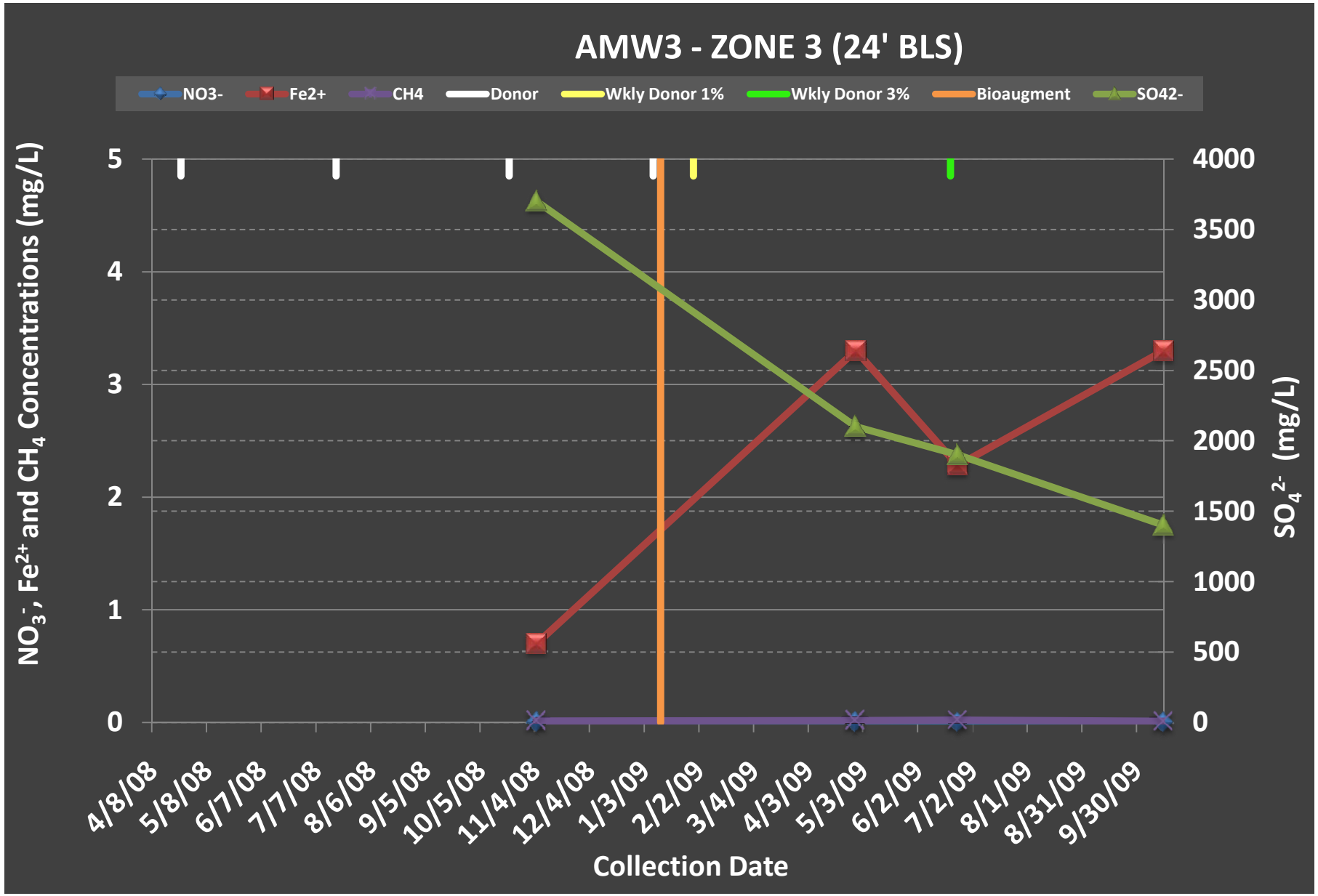
Recirculation system was shut off between 9/2/2008 and 1/6/2009.

Seal Beach
Groundwater Bioaugmentation



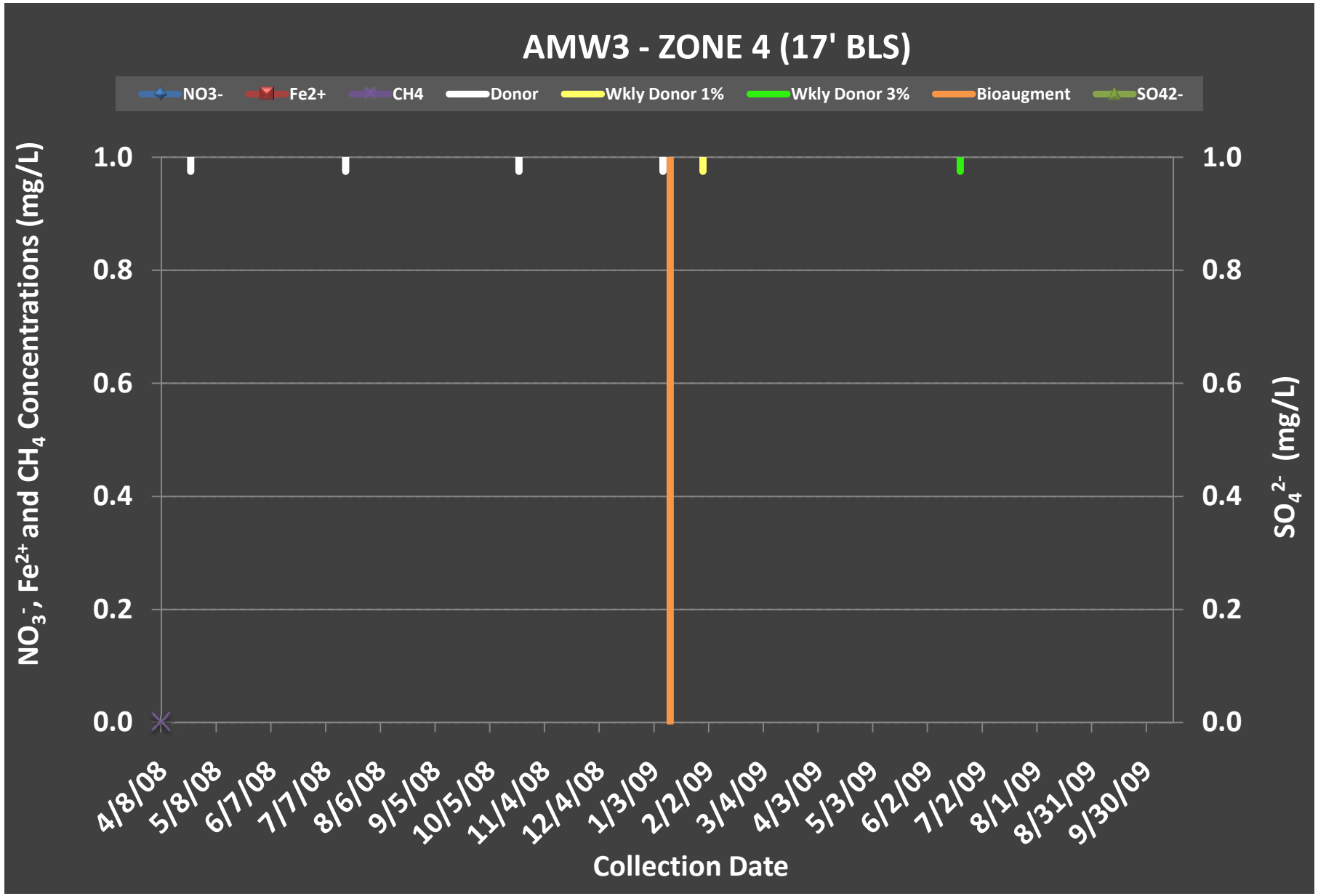
Recirculation system was shut off between 9/2/2008 and 1/6/2009.

Seal Beach
Groundwater Bioaugmentation



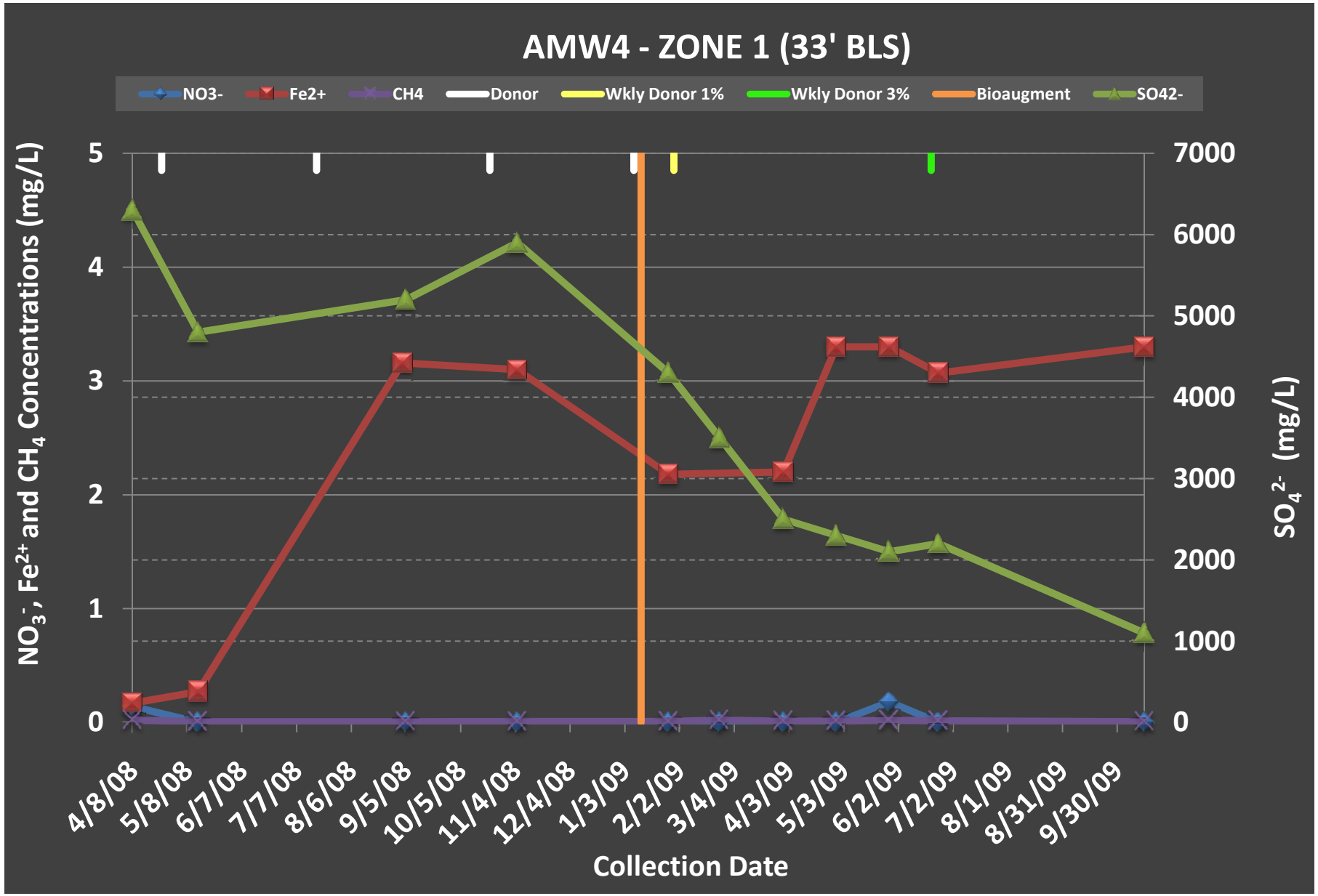
Recirculation system was shut off between 9/2/2008 and 1/6/2009.

Seal Beach
Groundwater Bioaugmentation



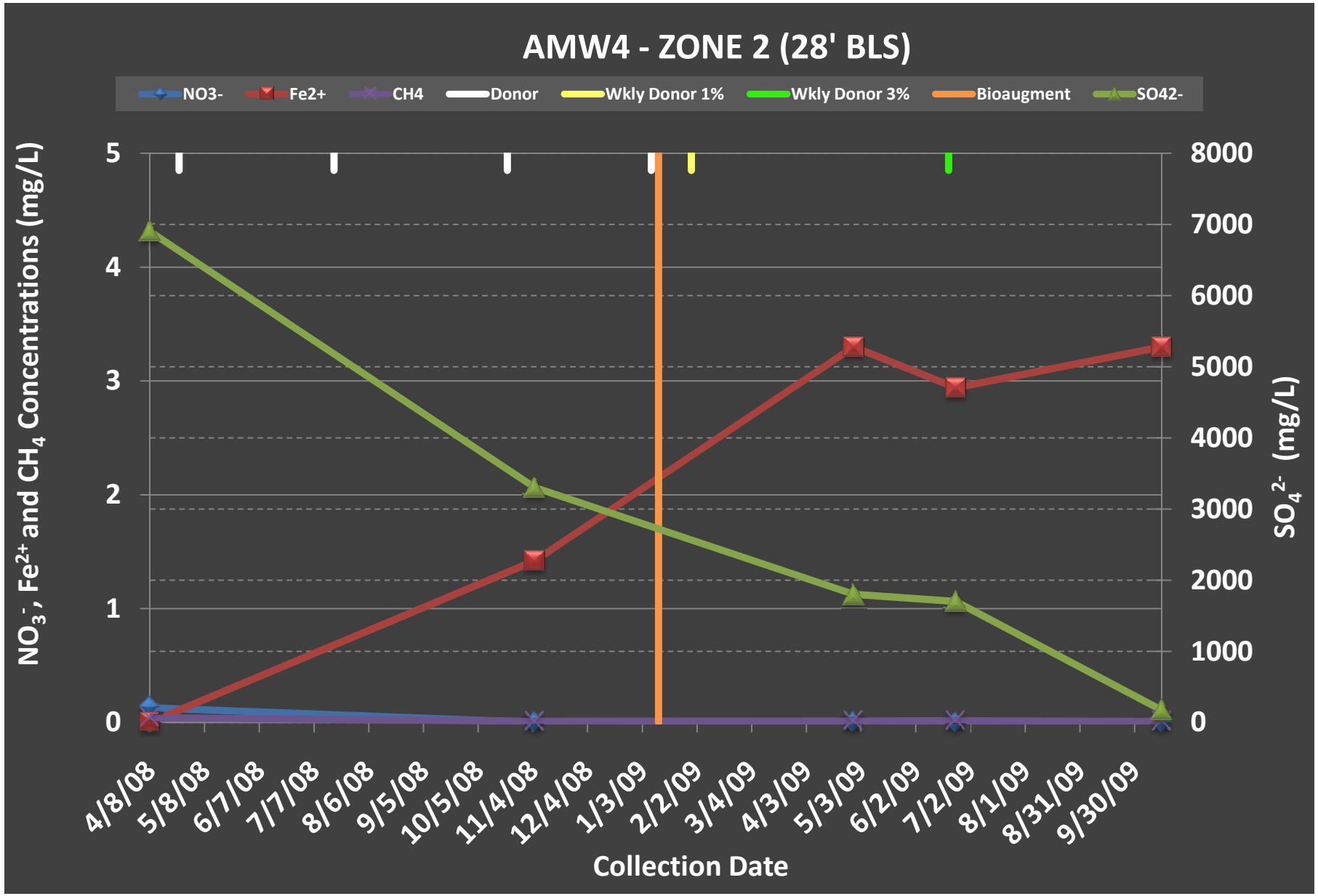
Recirculation system was shut off between 9/2/2008 and 1/6/2009.

Seal Beach
Groundwater Bioaugmentation



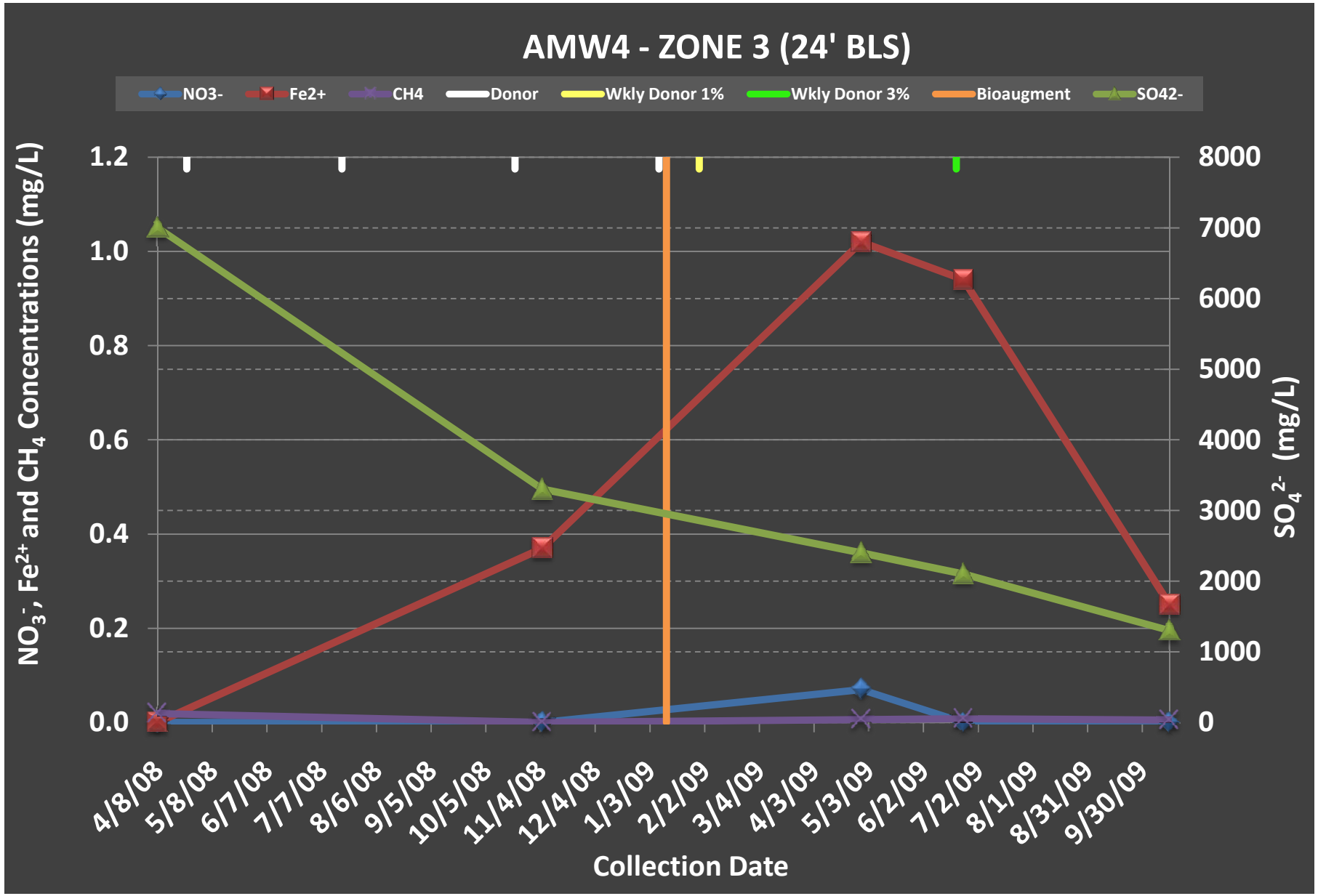
Recirculation system was shut off between 9/2/2008 and 1/6/2009.

Seal Beach
Groundwater Bioaugmentation



Recirculation system was shut off between 9/2/2008 and 1/6/2009.

Seal Beach
Groundwater Bioaugmentation



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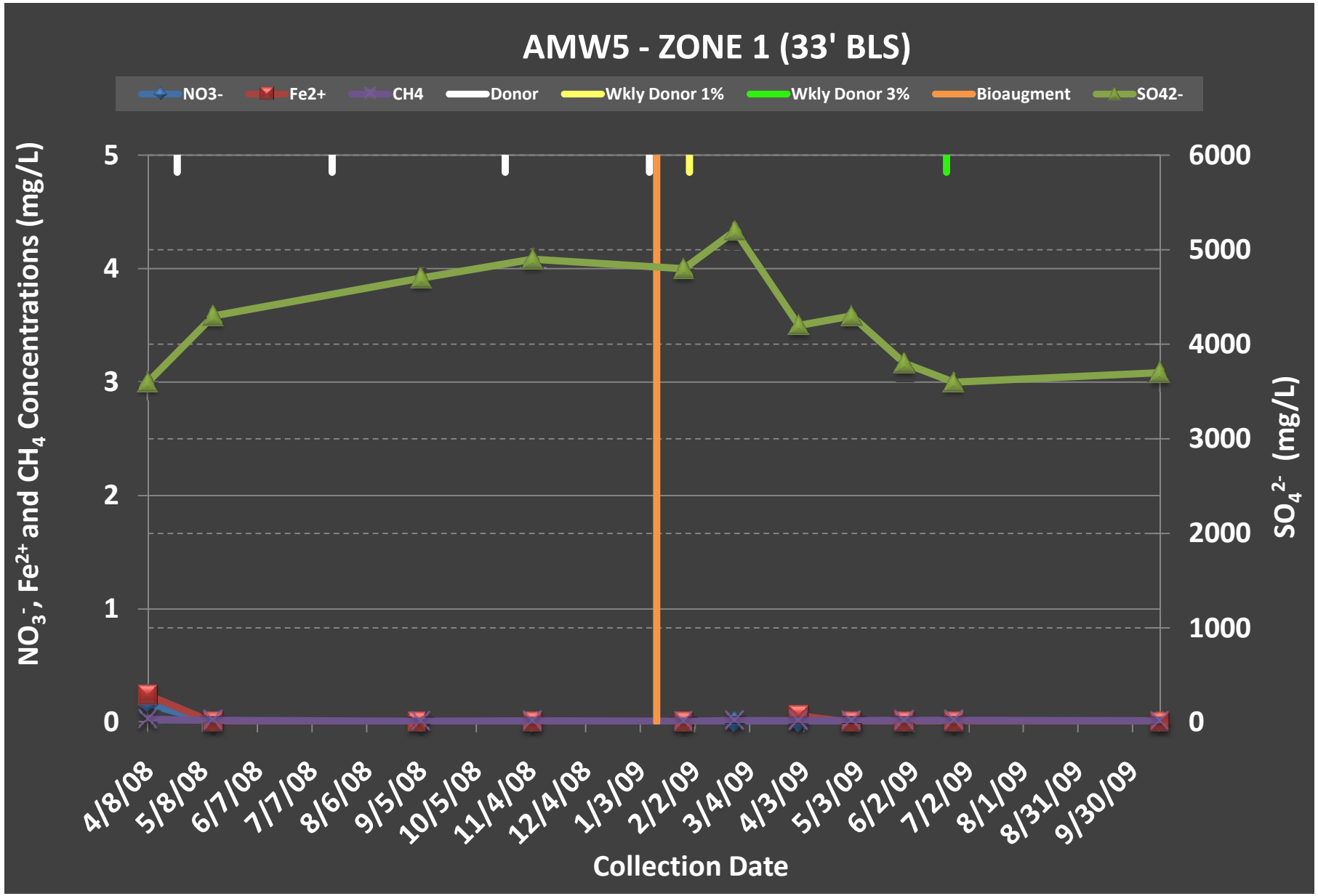
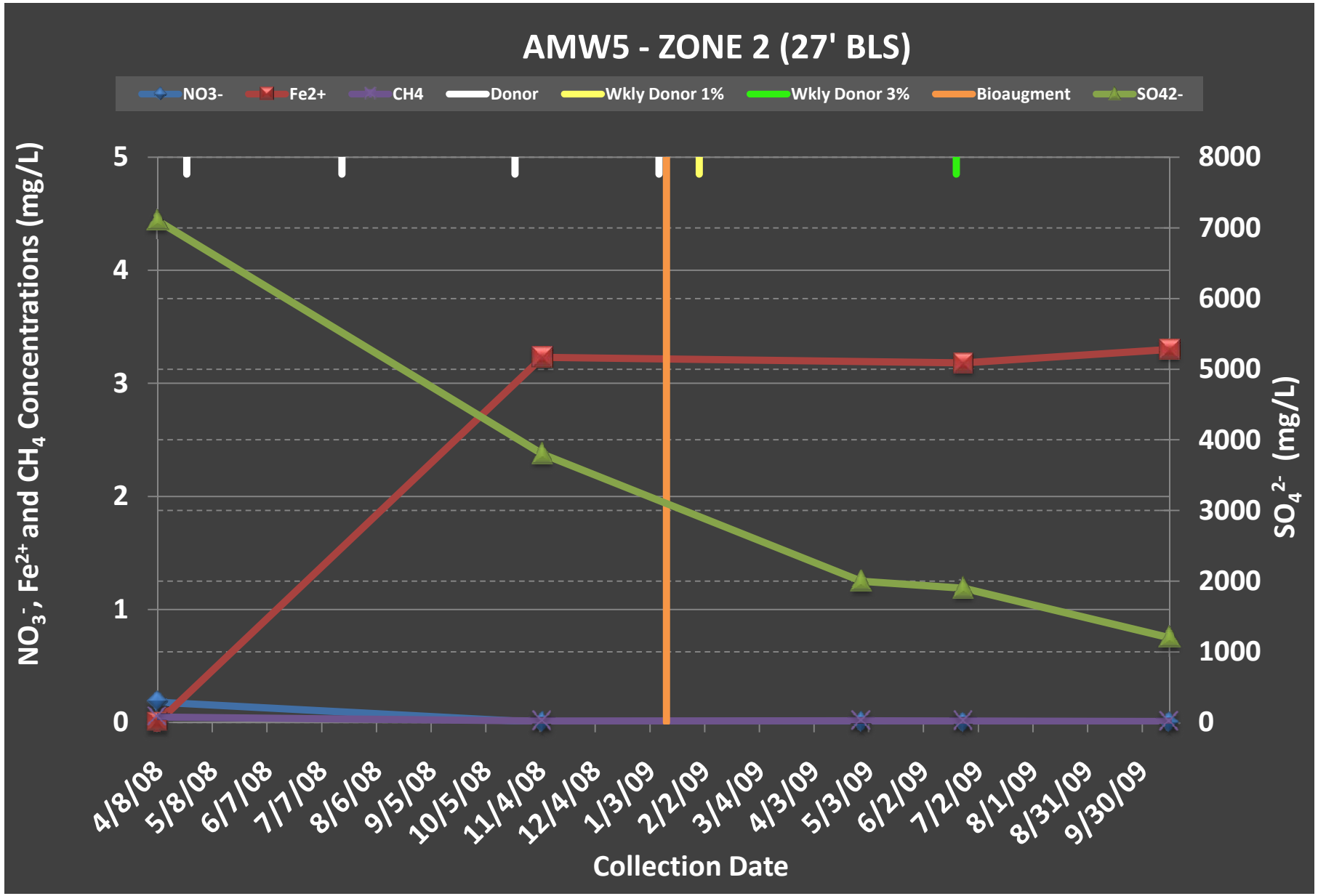
Seal Beach
Groundwater Bioaugmentation



Recirculation system was shut off between 9/2/2008 and 1/6/2009.

Seal Beach
Groundwater Bioaugmentation



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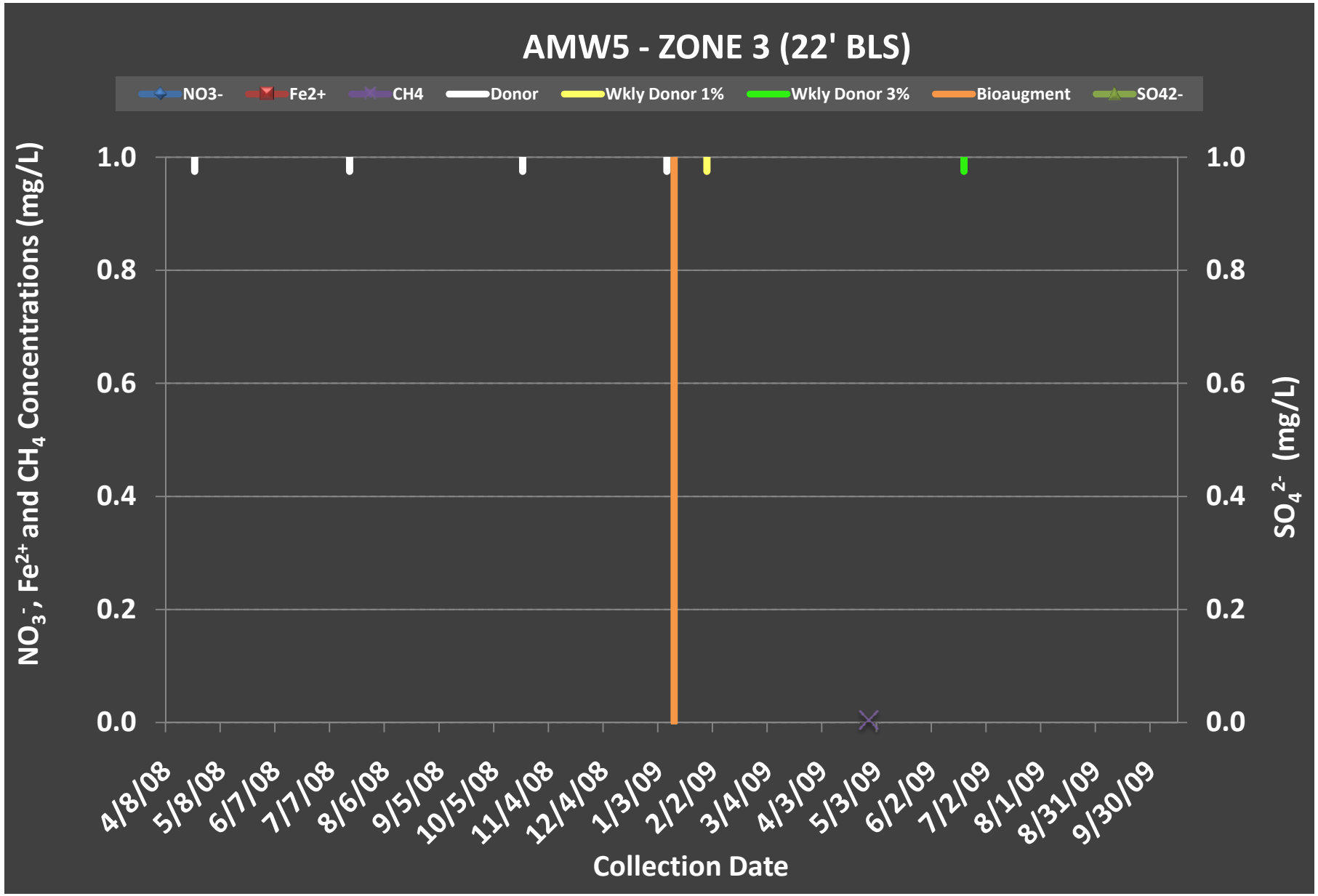
Seal Beach
Groundwater Bioaugmentation



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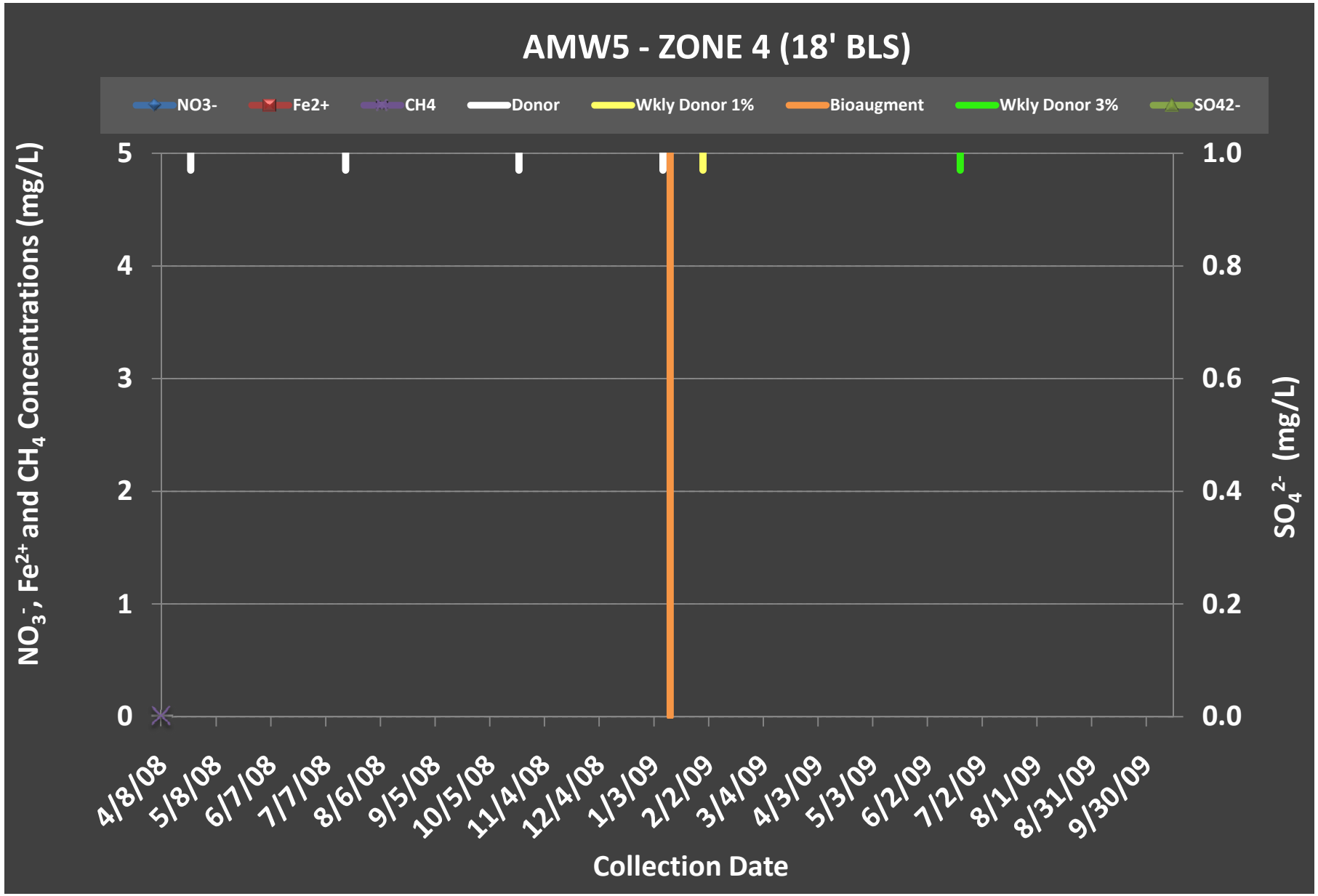
Seal Beach
Groundwater Bioaugmentation



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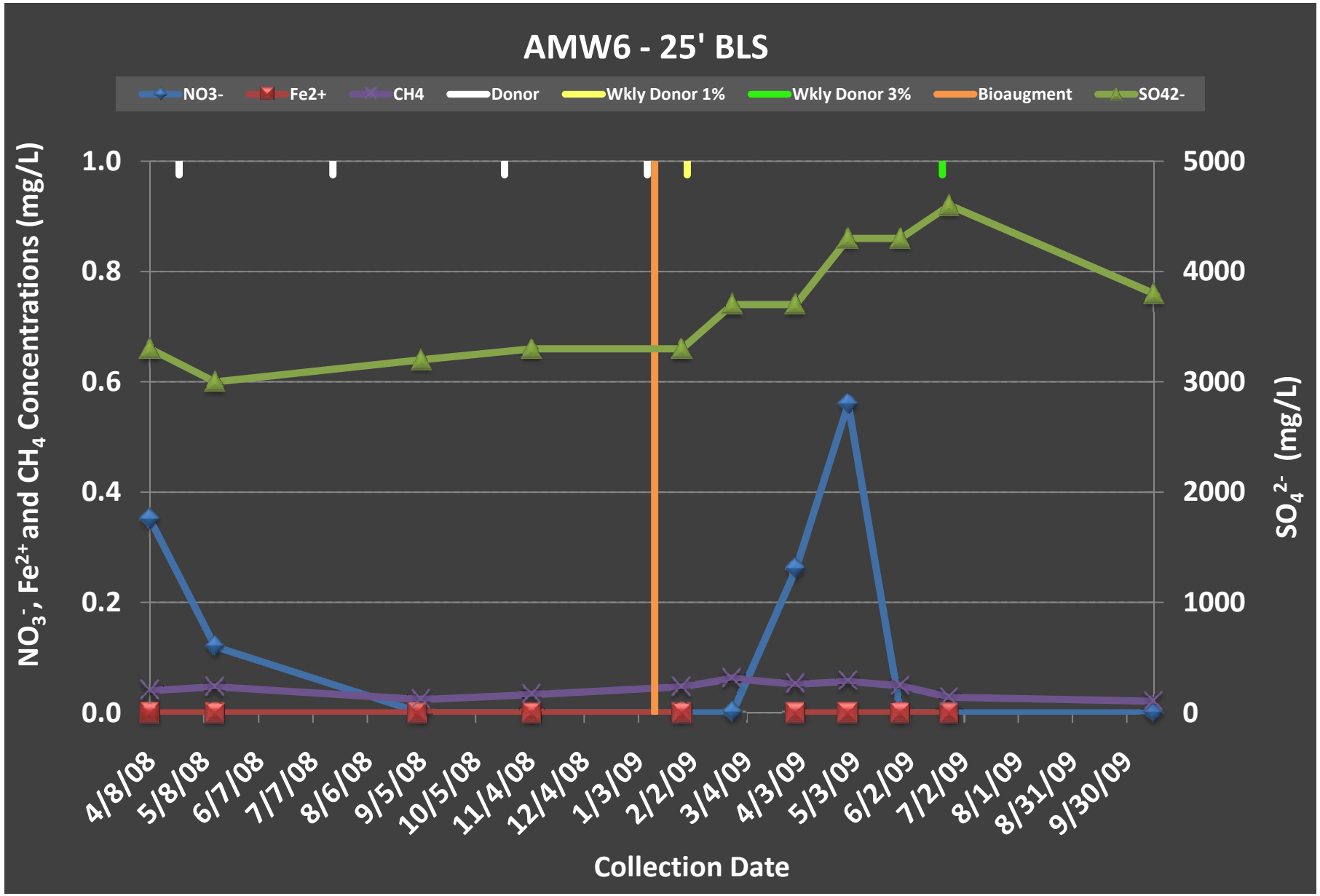
Seal Beach
Groundwater Bioaugmentation



Recirculation system was shut off between 9/2/2008 and 1/6/2009.

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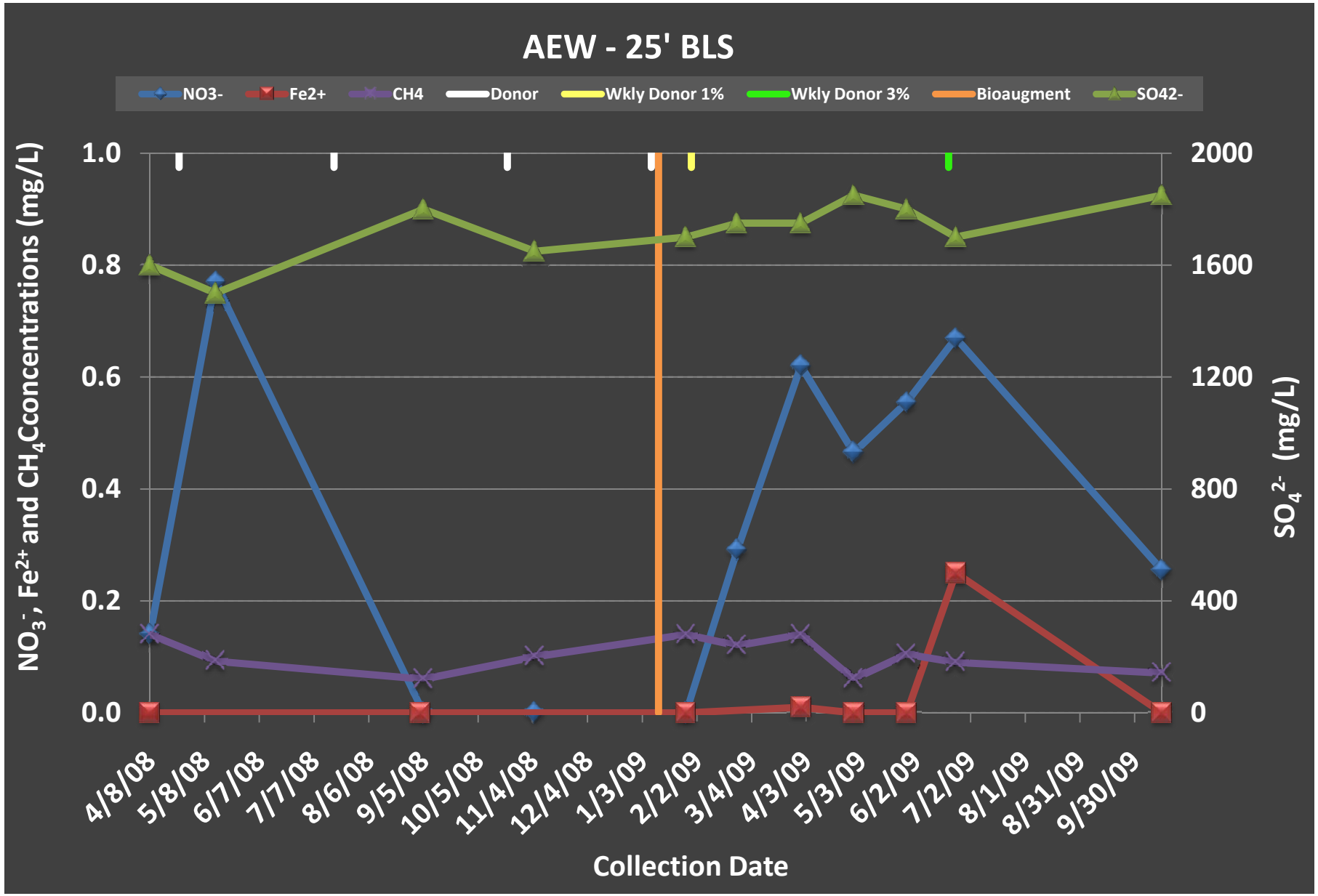
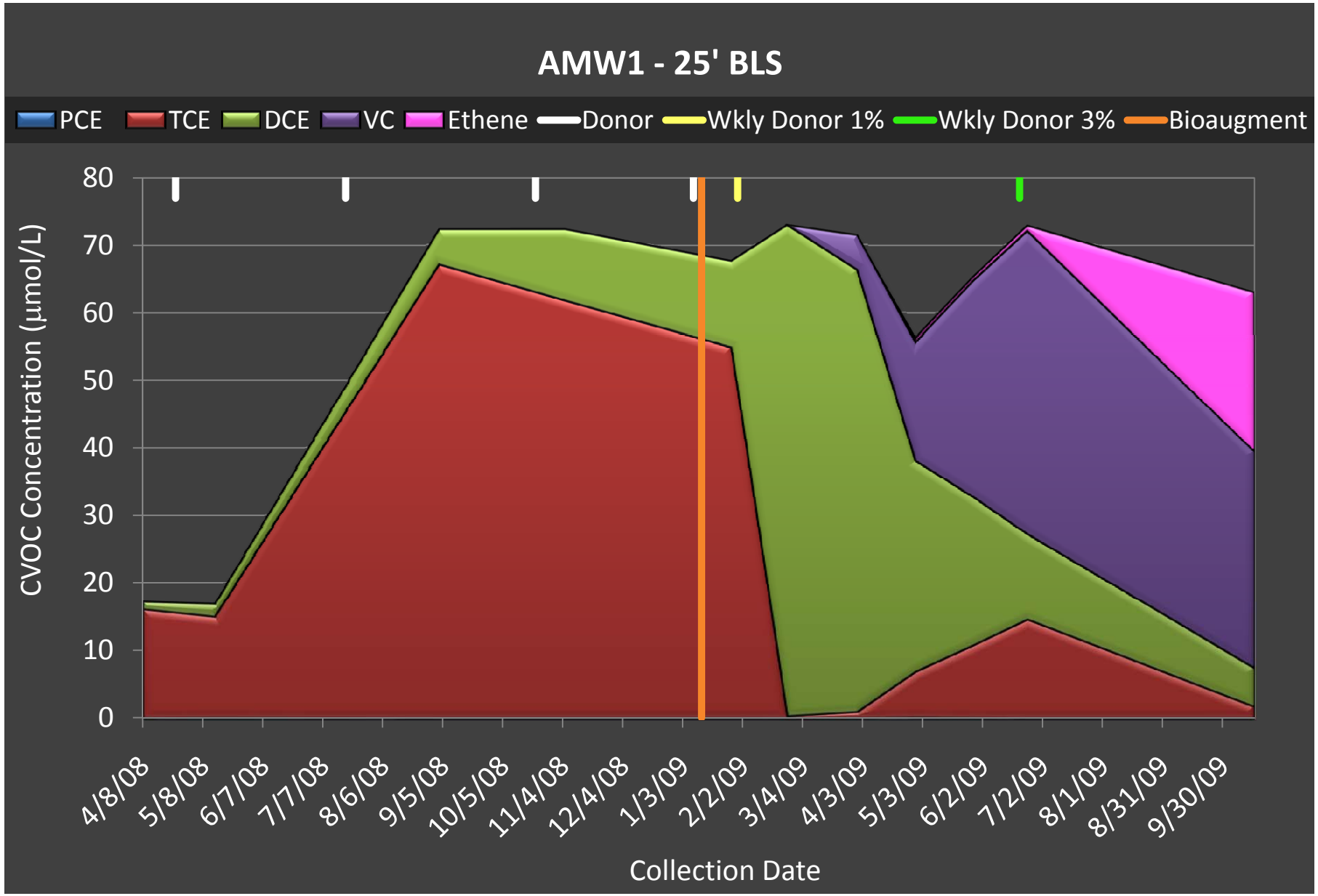
Seal Beach
Groundwater Bioaugmentation



Recirculation system was shut off between 9/2/2008 and 1/6/2009.

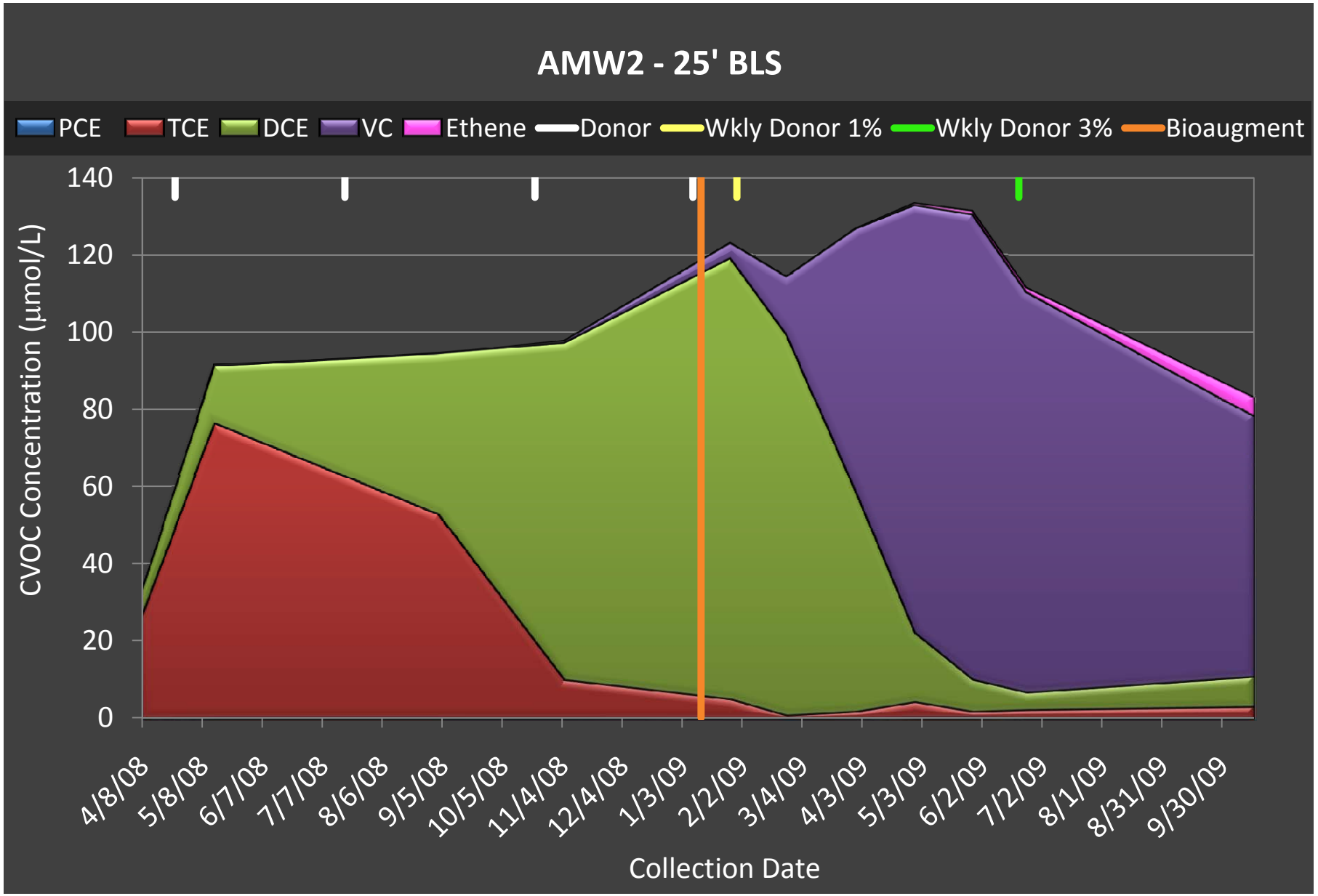
CVOCs Molar Concentrations

Seal Beach
Groundwater Bioaugmentation



Recirculation system was shut off between 9/2/2008 and 1/6/2009.

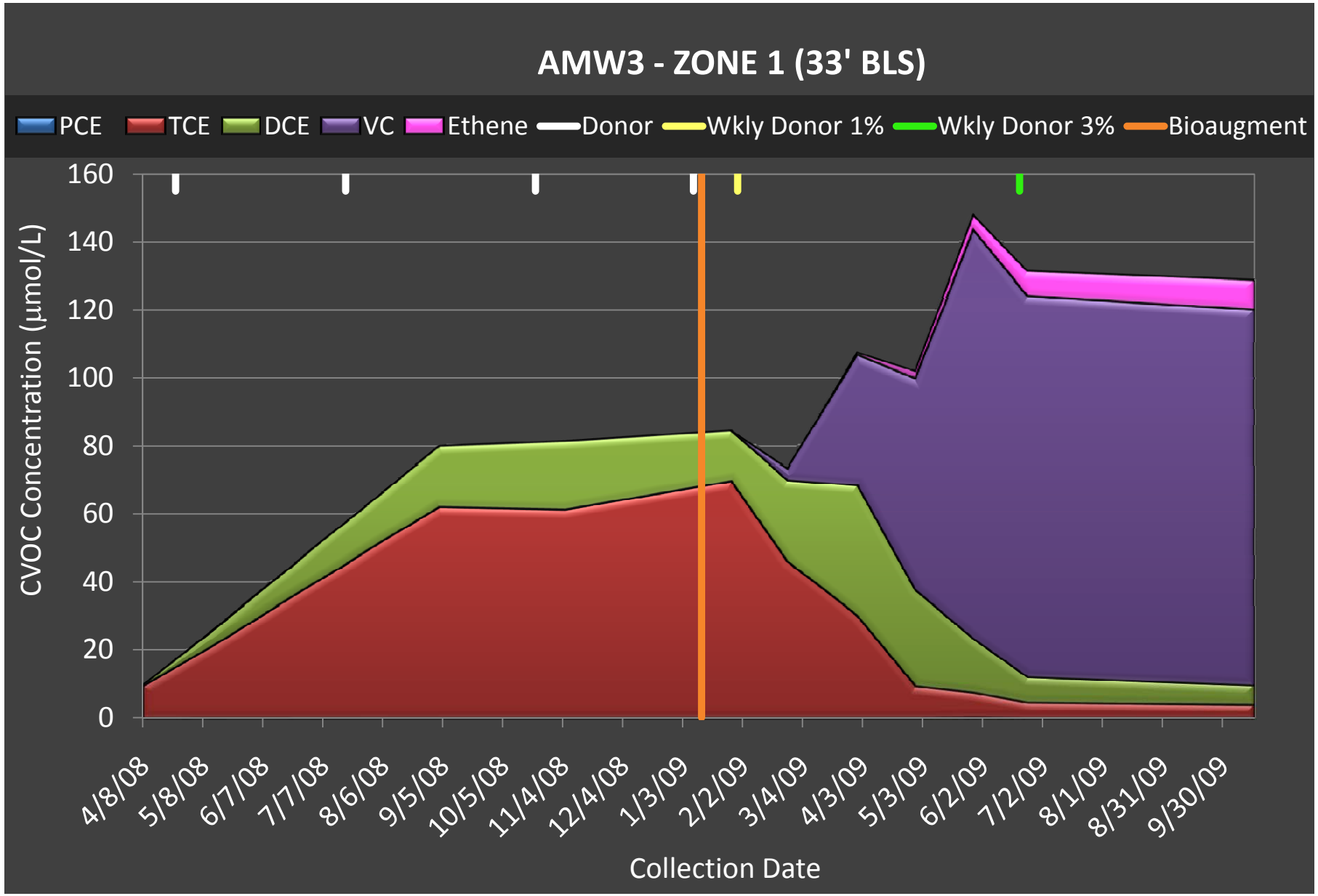
Seal Beach
Groundwater Bioaugmentation



Recirculation system was shut off between 9/2/2008 and 1/6/2009.

AMW2-25, Dechlorination_molar_Act_Seal Beach_Oct 2009.xlsx

Seal Beach
Groundwater Bioaugmentation



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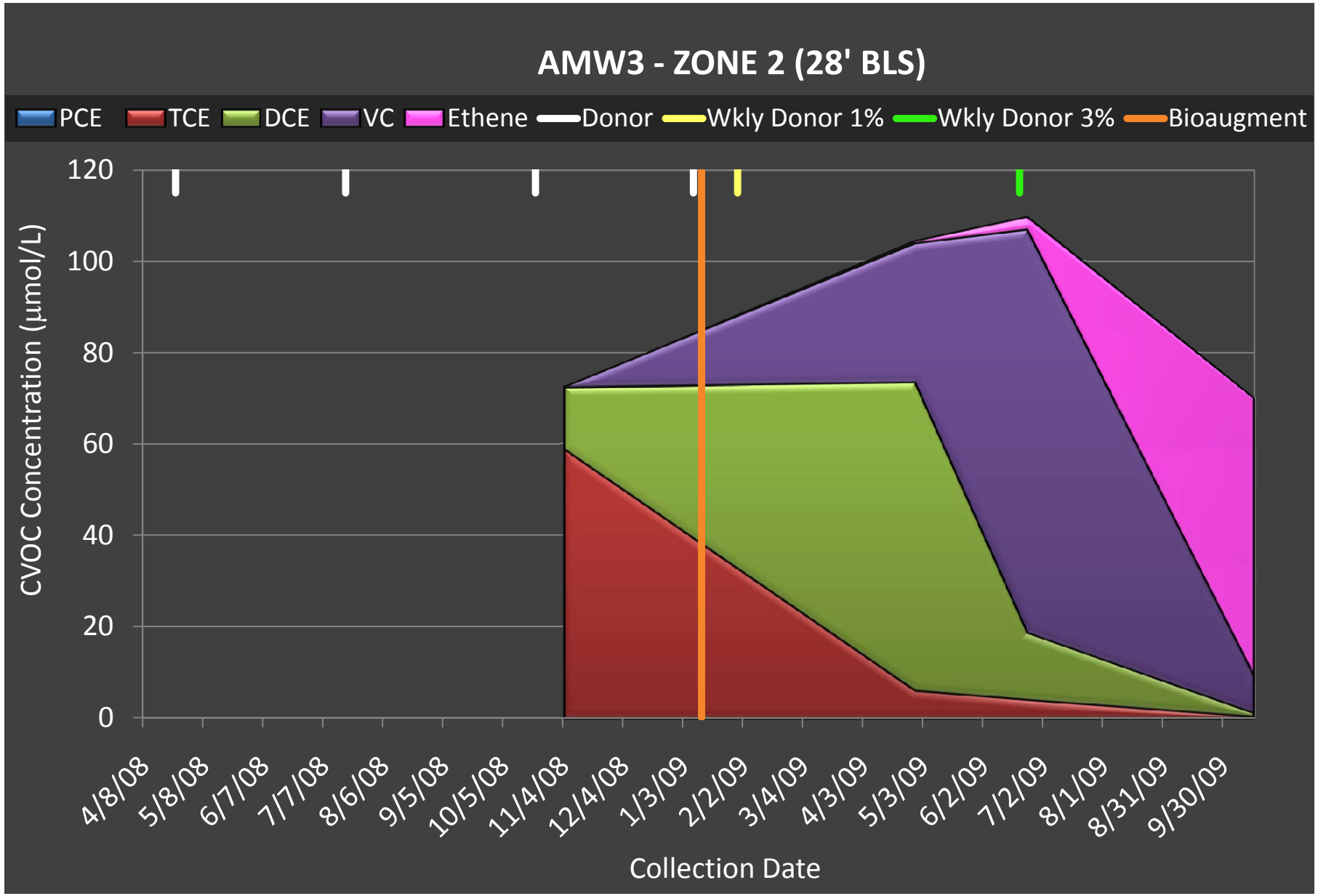
Seal Beach
Groundwater Bioaugmentation



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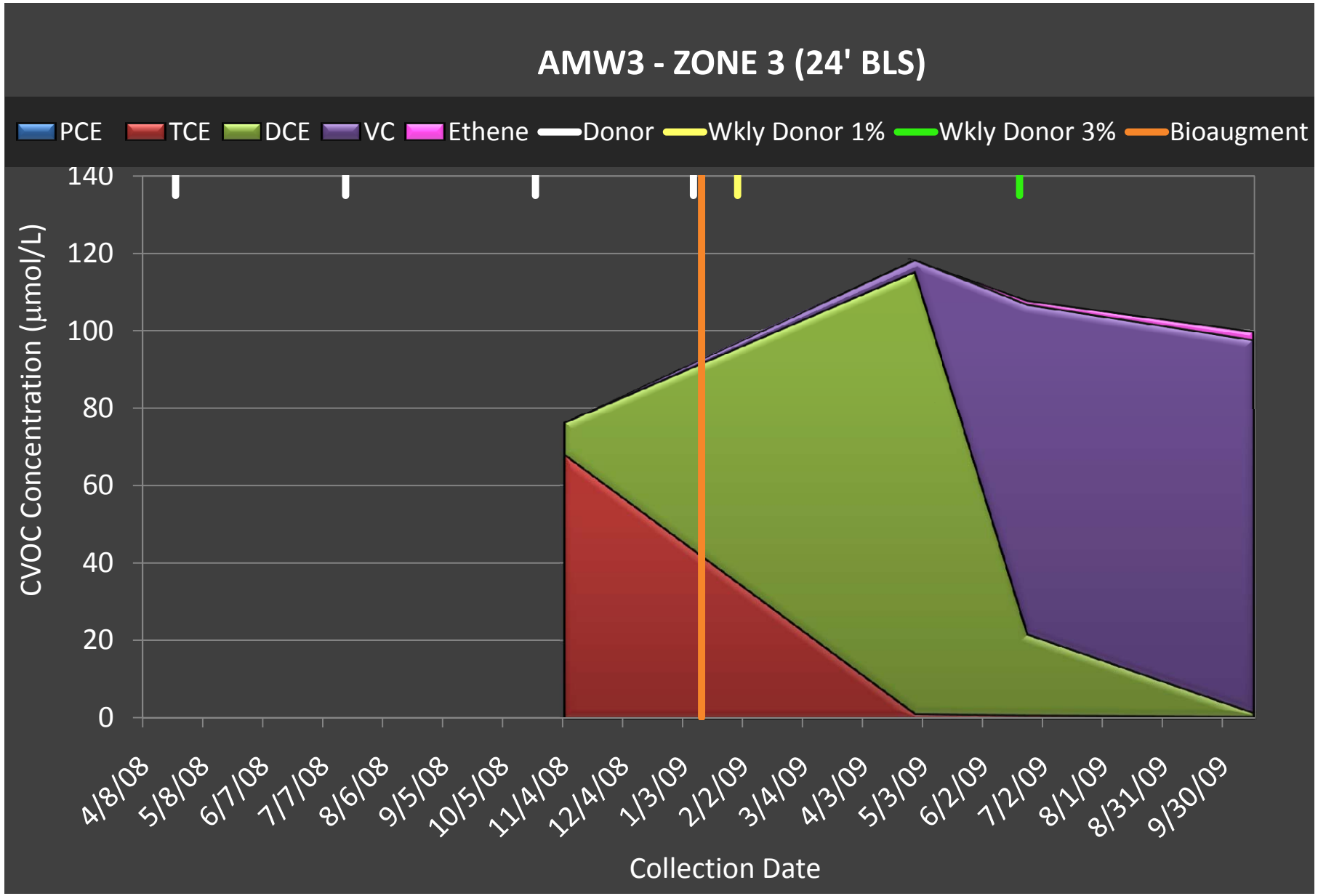
Seal Beach
Groundwater Bioaugmentation



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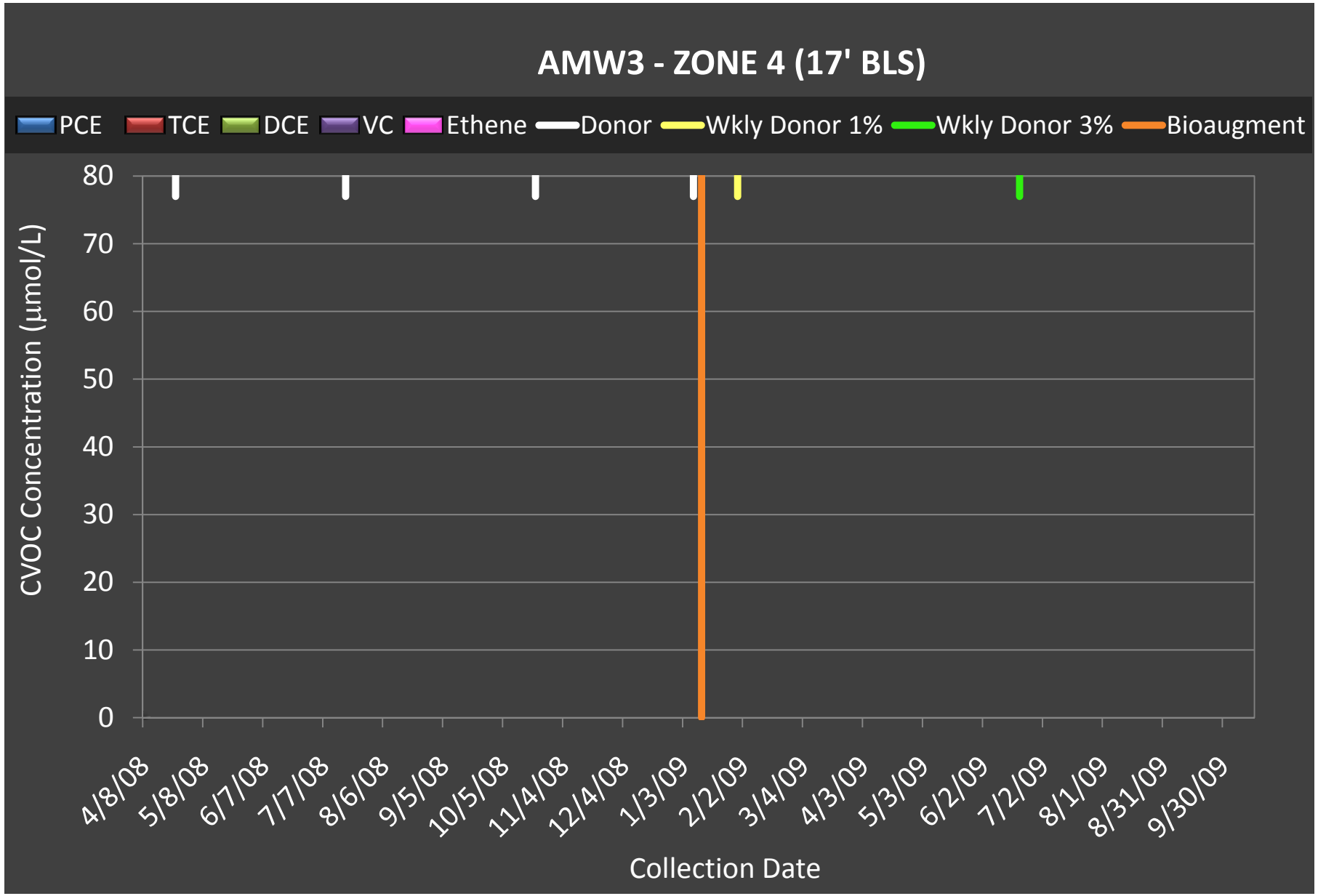
Seal Beach
Groundwater Bioaugmentation



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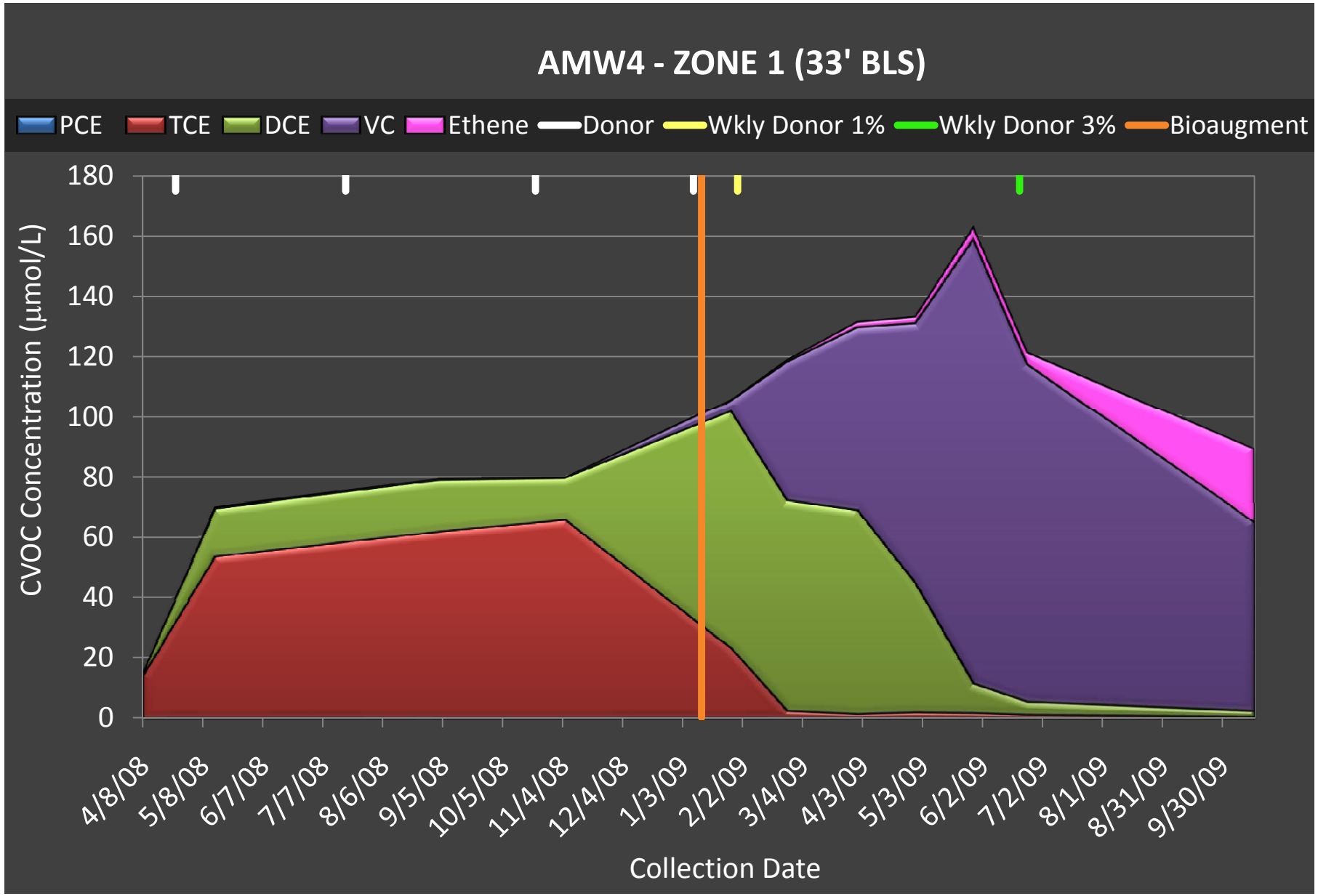
Seal Beach
Groundwater Bioaugmentation



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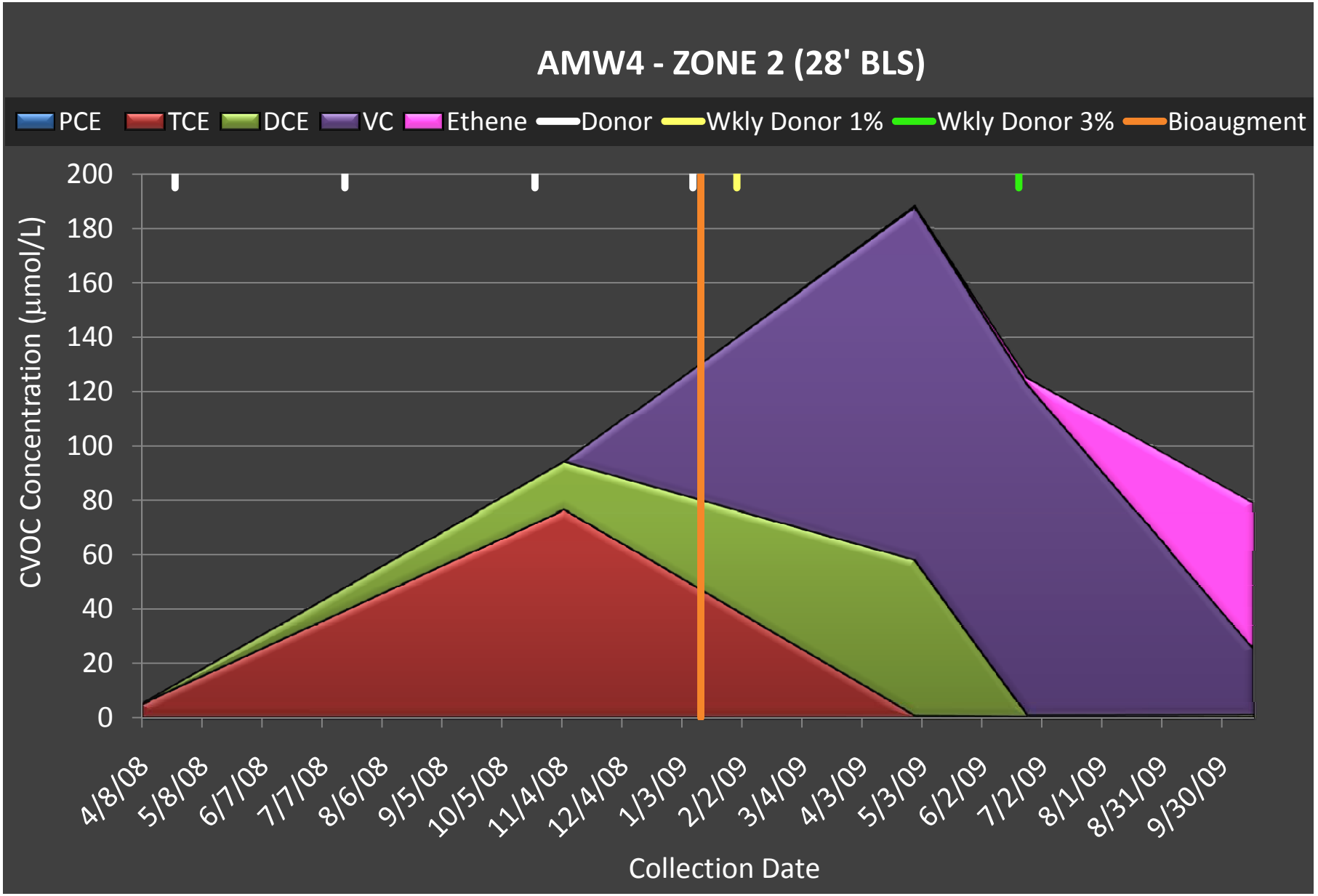
Seal Beach
Groundwater Bioaugmentation



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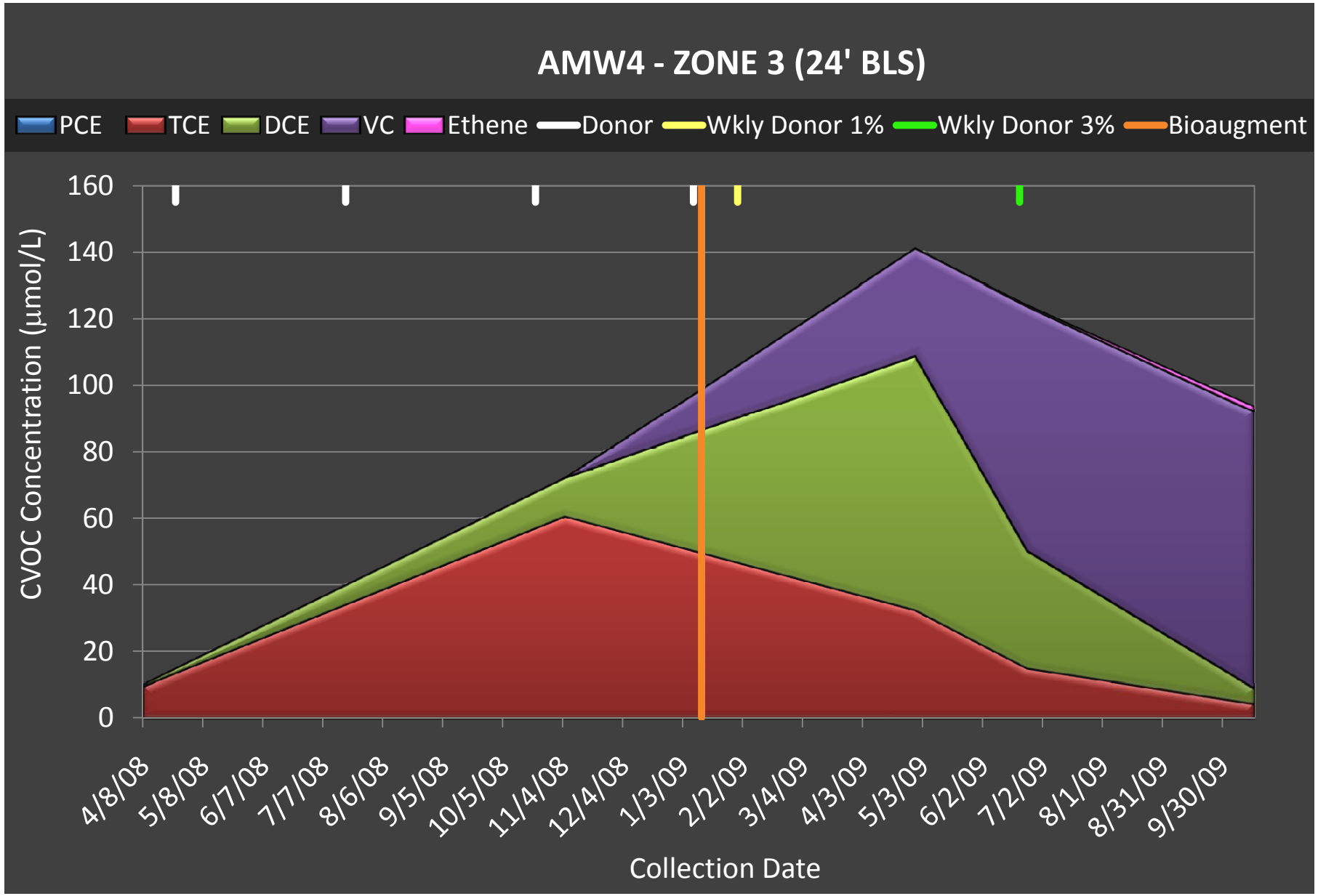
Seal Beach
Groundwater Bioaugmentation



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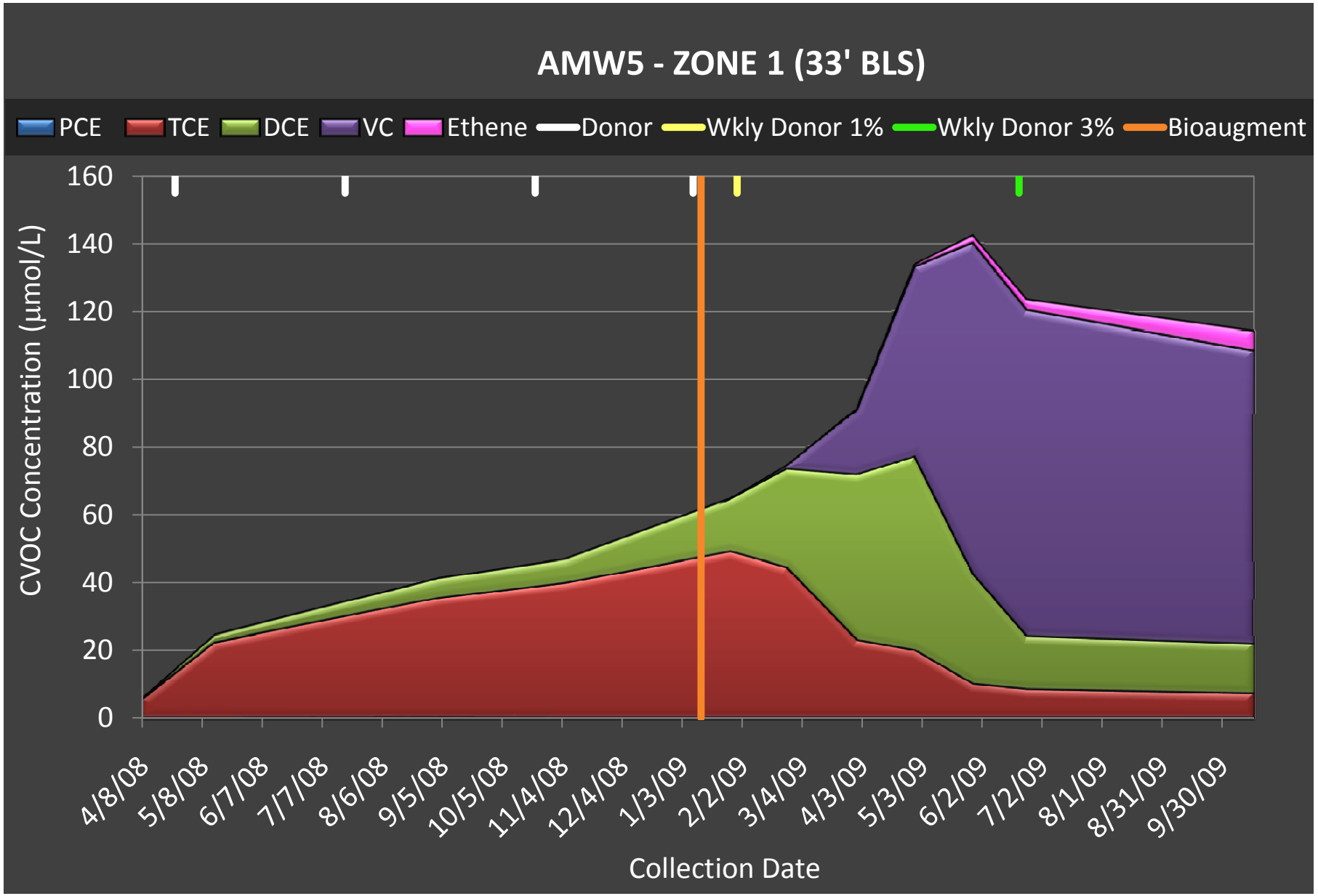
Seal Beach
Groundwater Bioaugmentation



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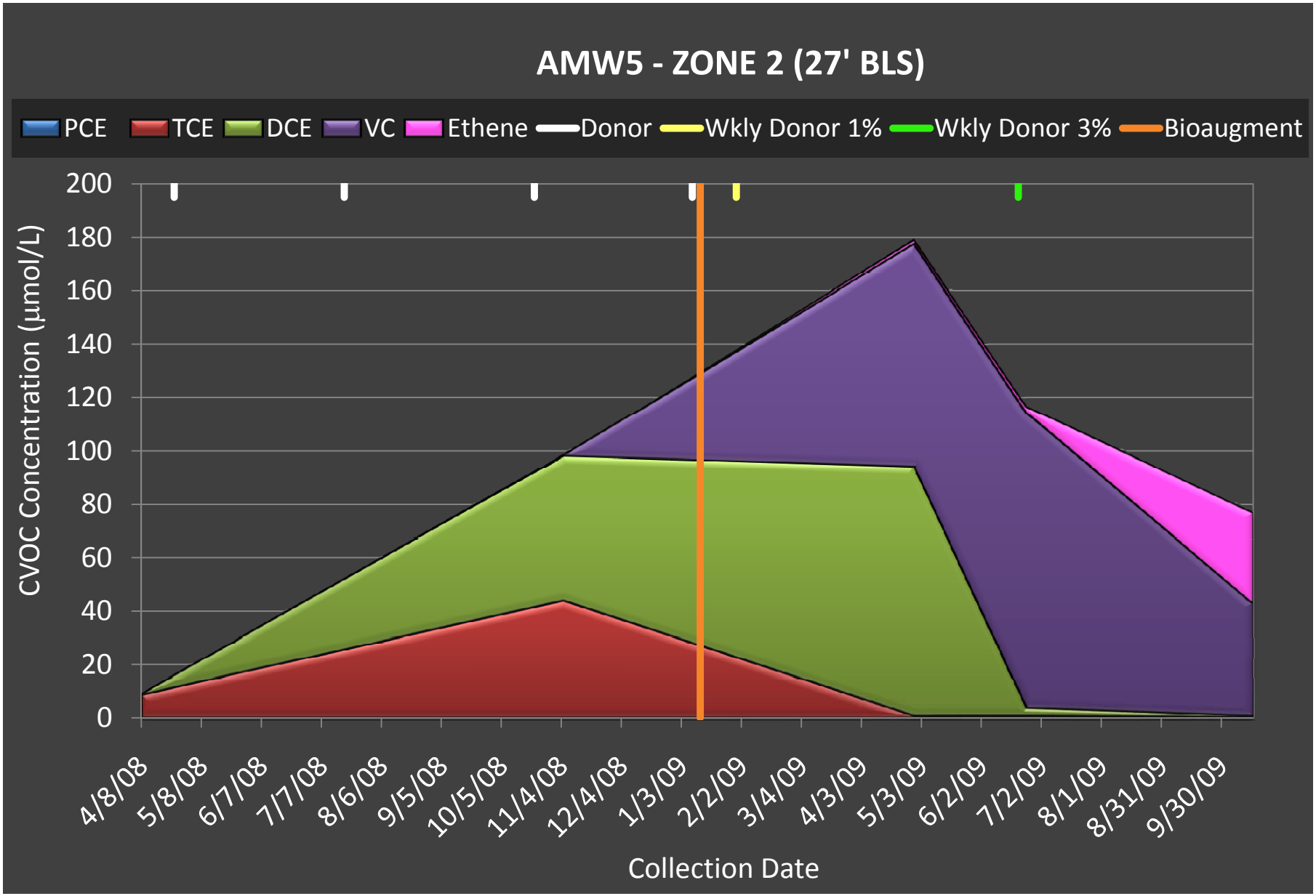
Seal Beach
Groundwater Bioaugmentation



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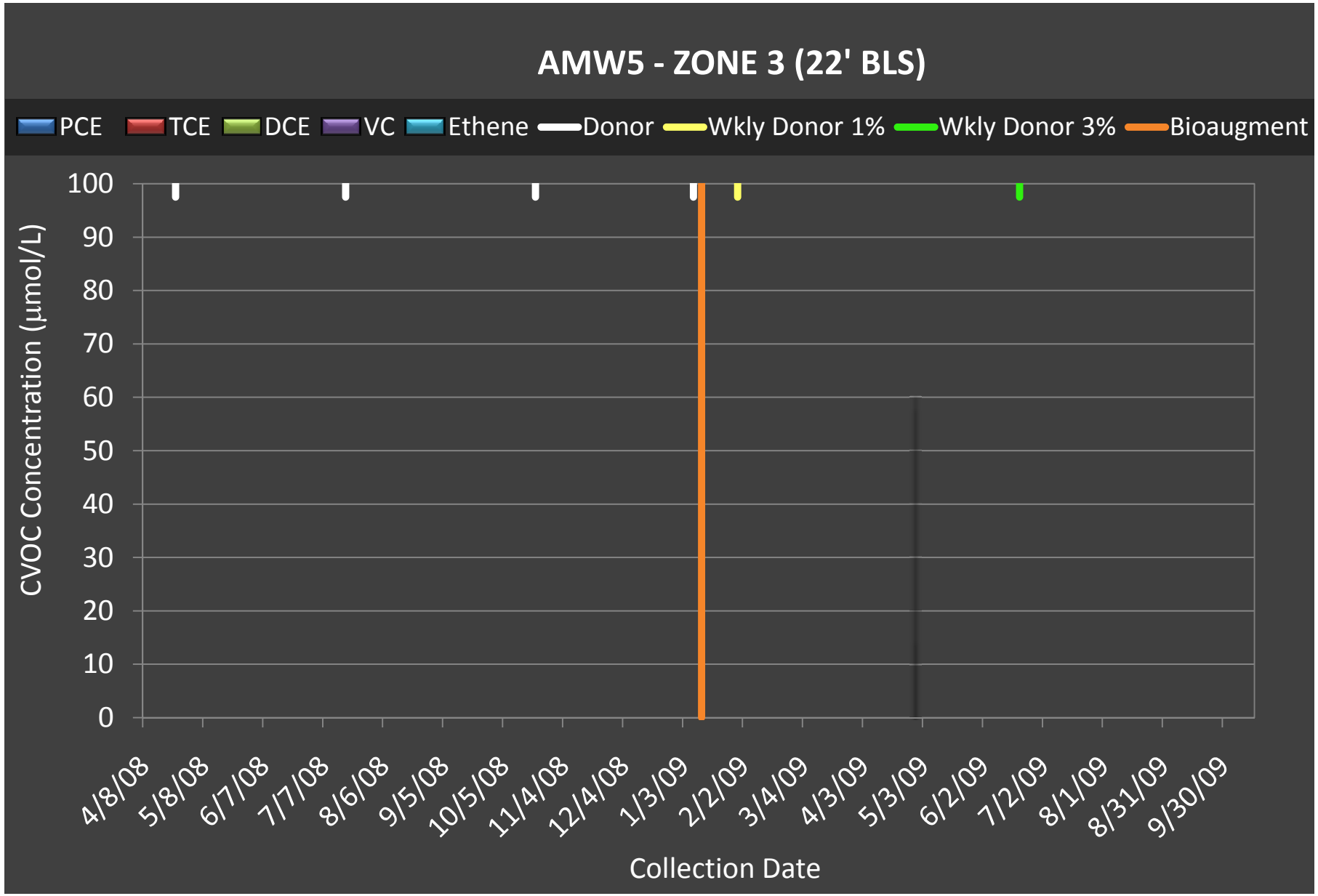
Seal Beach
Groundwater Bioaugmentation



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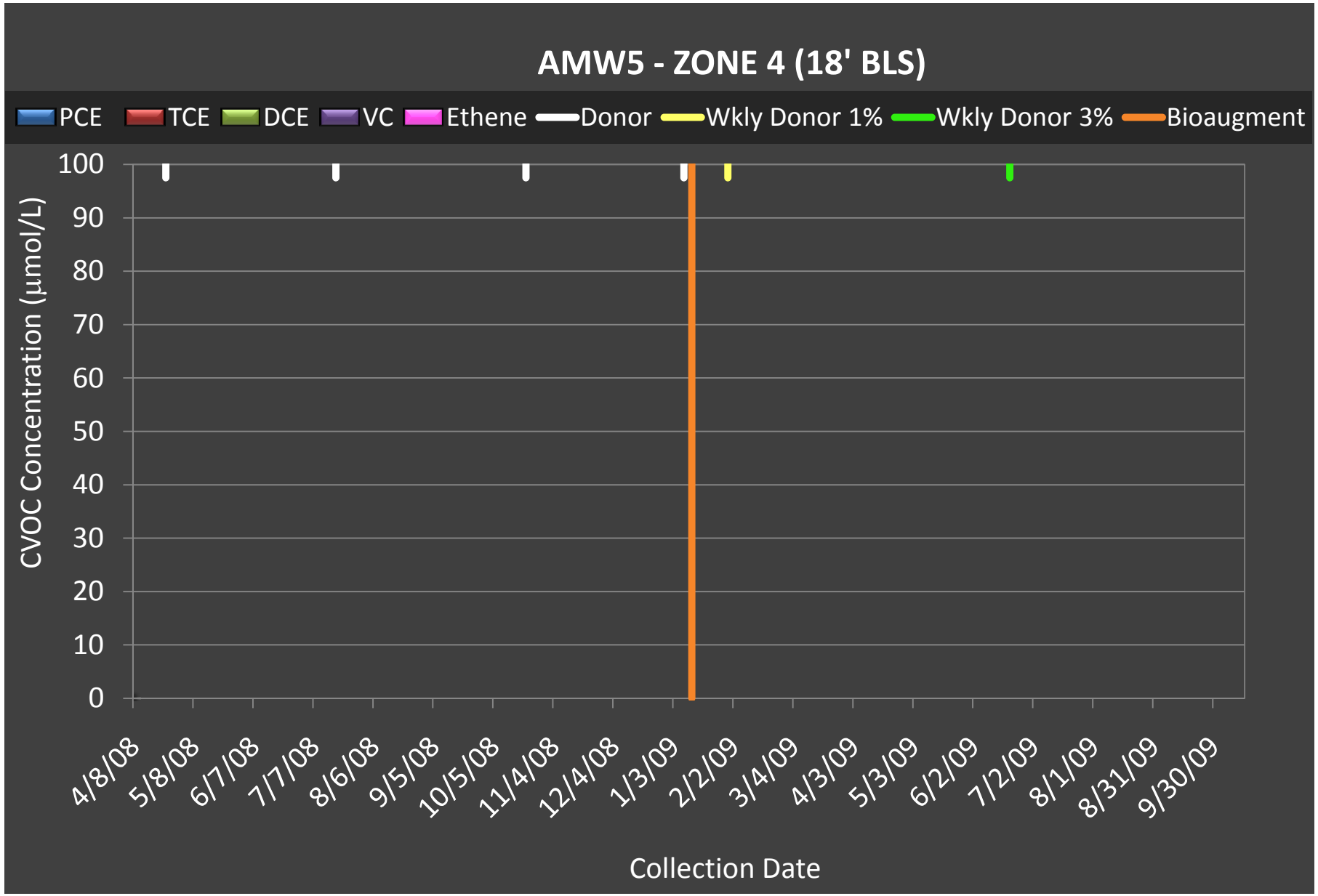
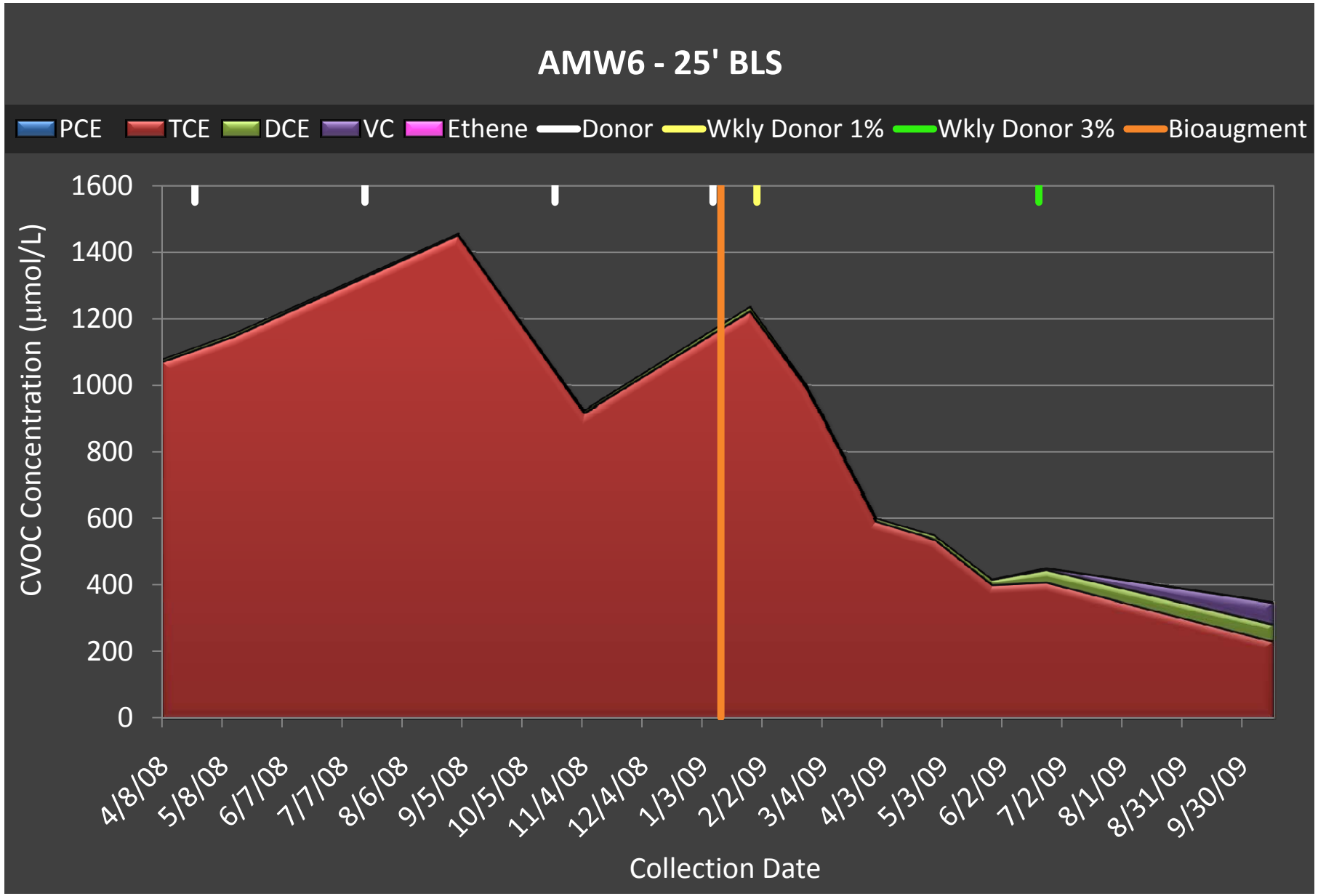
Seal Beach
Groundwater Bioaugmentation



Recirculation system was shut off between 9/2/2008 and 1/6/2009.

AMW5-Z4, Dechlorination_molar_Act_Seal Beach_Oct 2009.xlsx

Seal Beach
Groundwater Bioaugmentation



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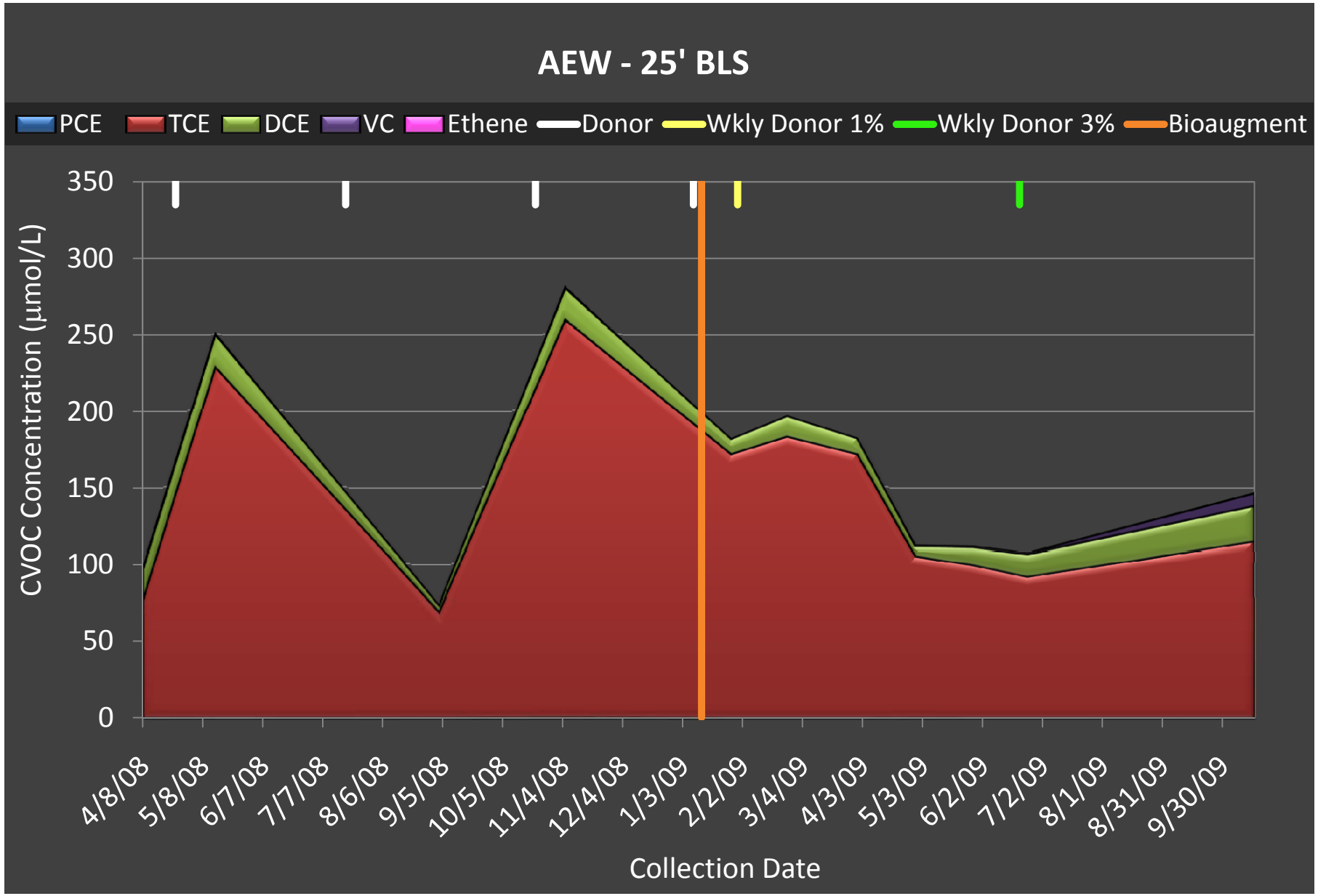
Seal Beach
Groundwater Bioaugmentation



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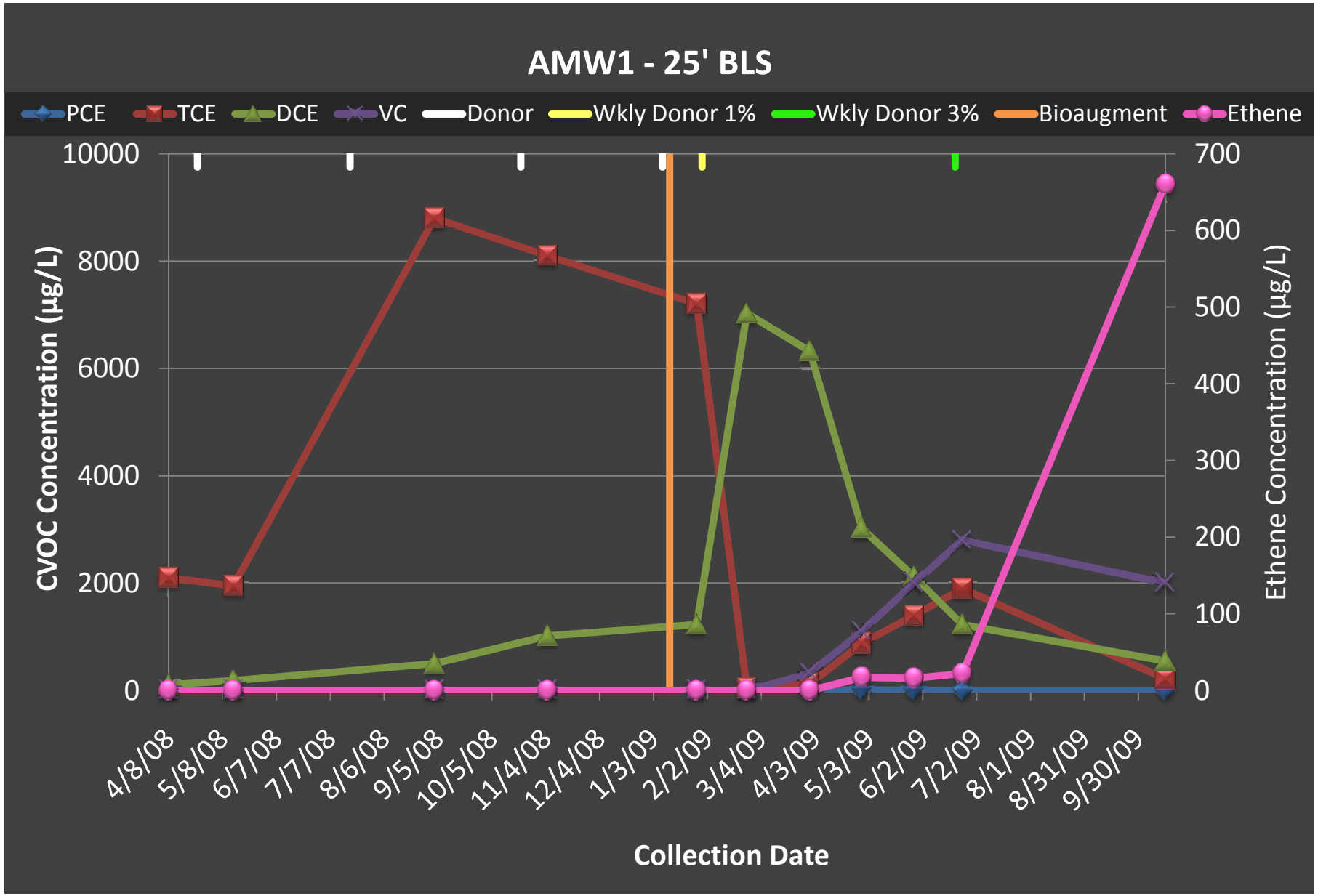
CVOCs Mass Concentrations

Seal Beach
Groundwater Bioaugmentation



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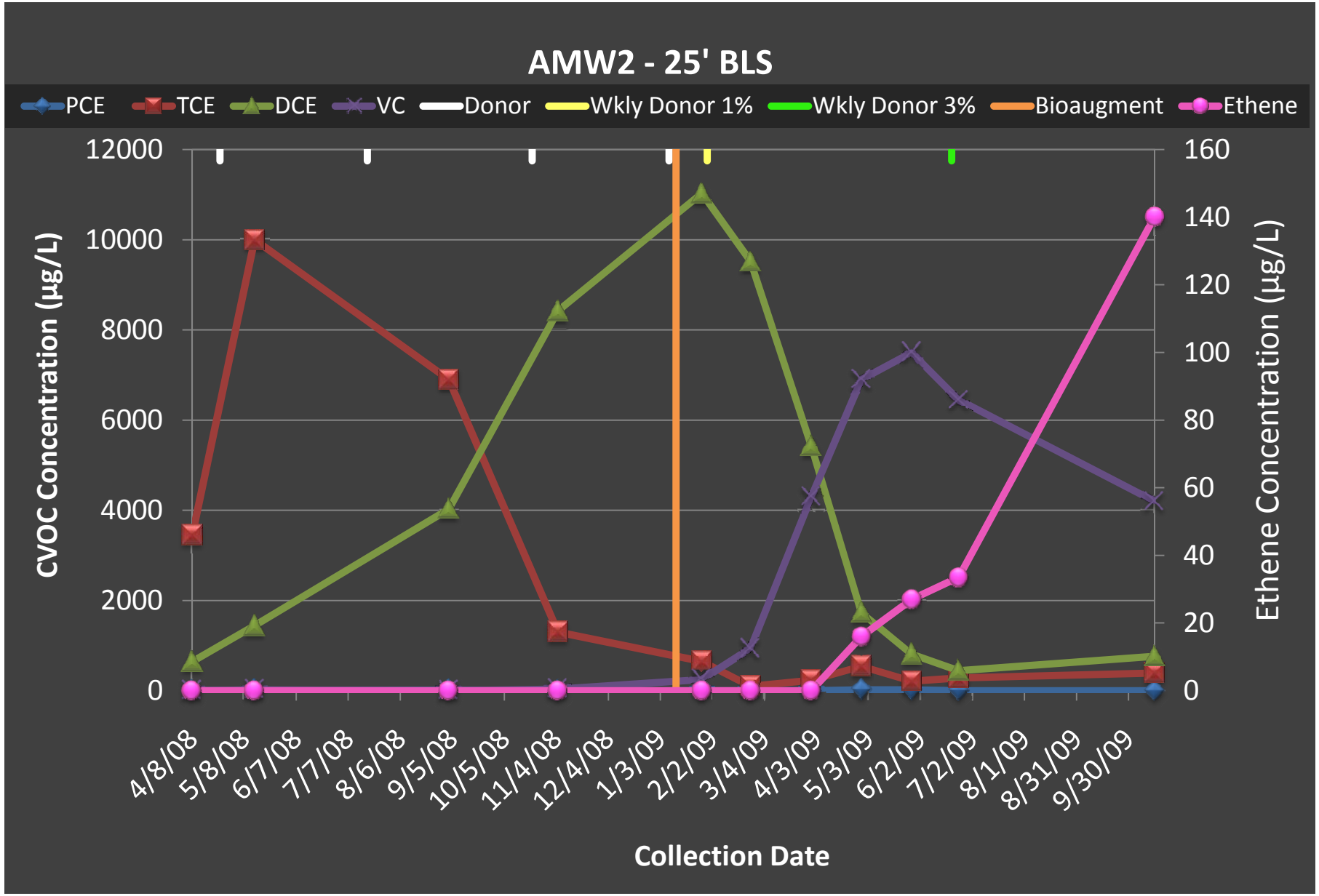
Seal Beach
Groundwater Bioaugmentation



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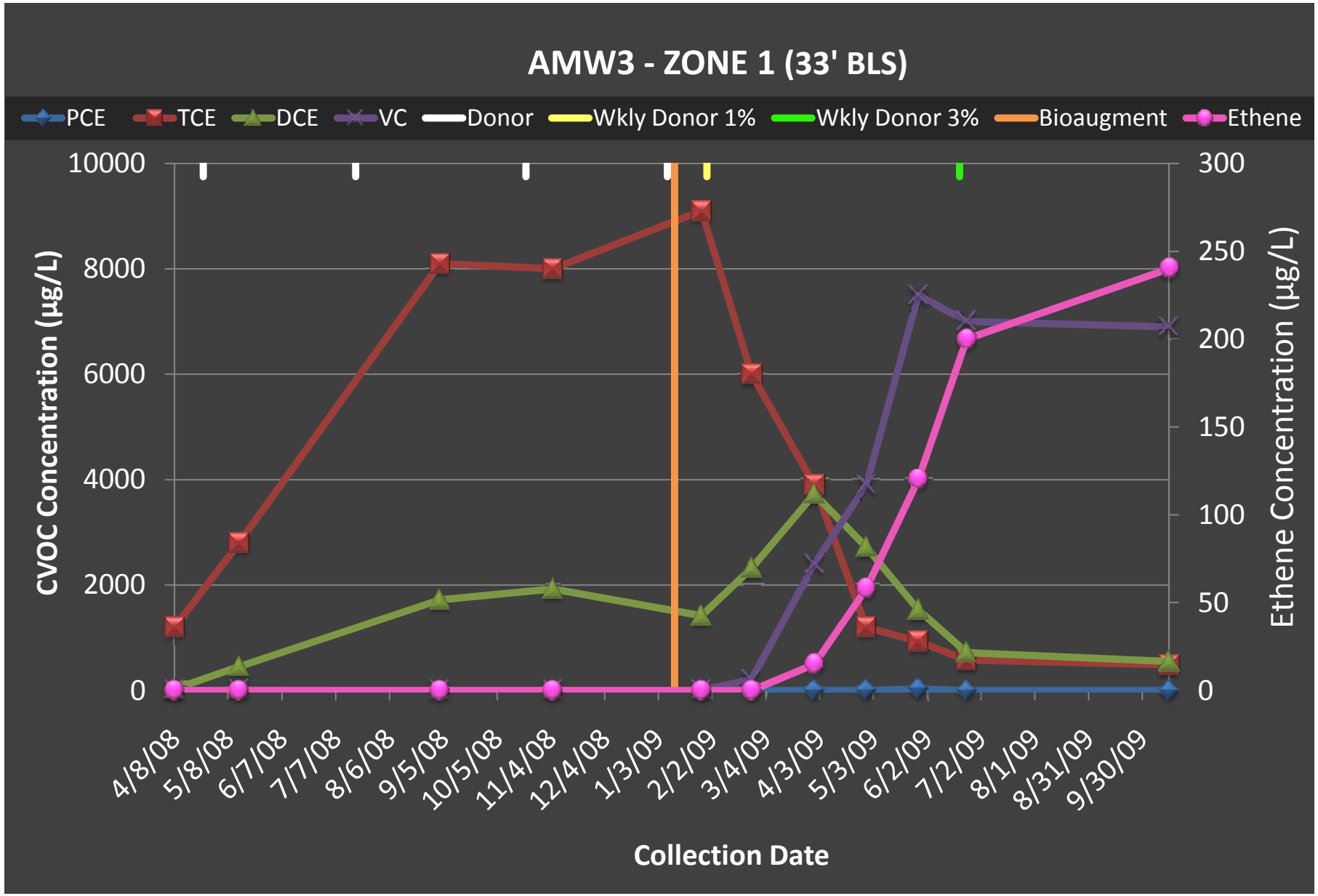
Seal Beach
Groundwater Bioaugmentation



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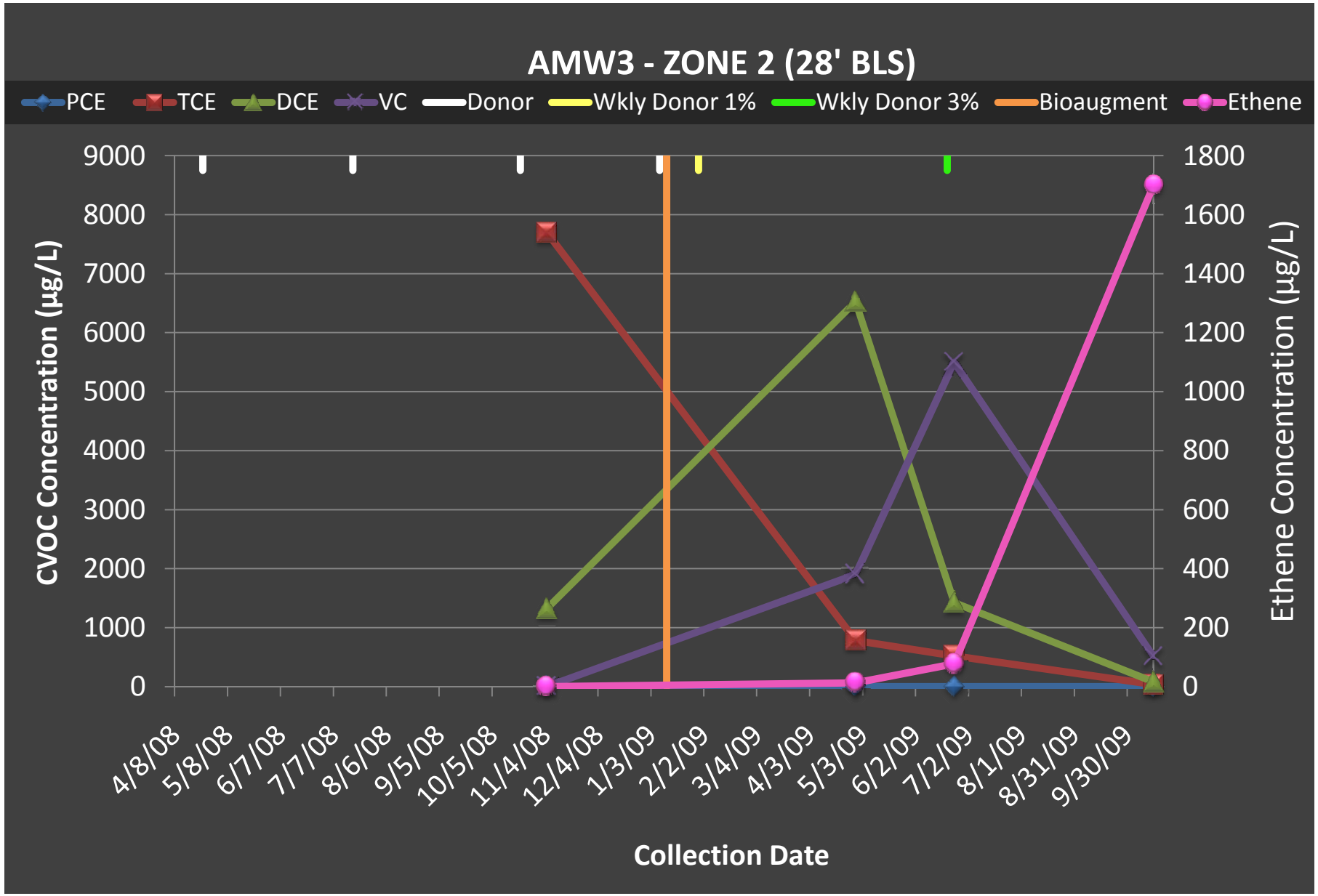
Seal Beach
Groundwater Bioaugmentation



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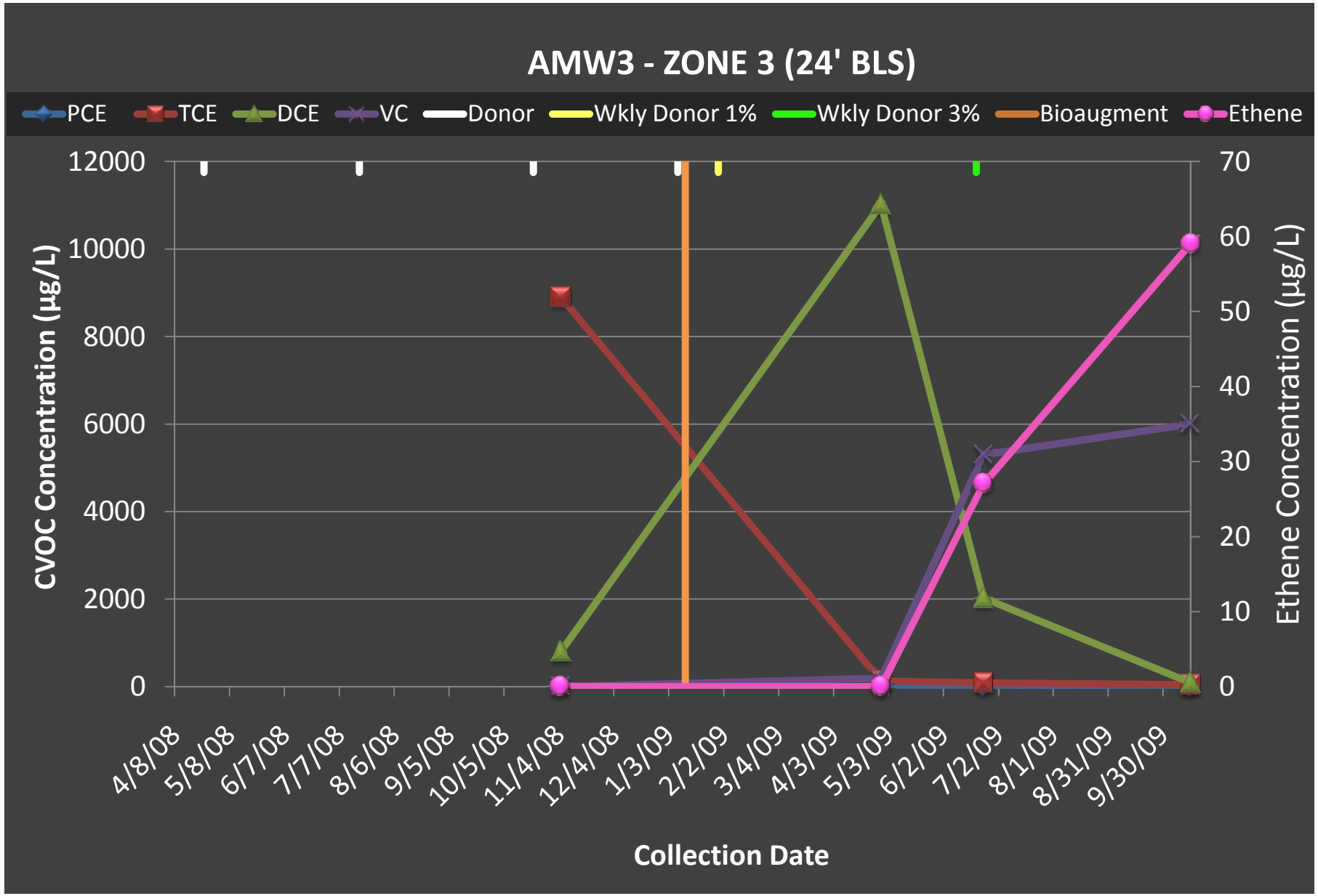
Seal Beach
Groundwater Bioaugmentation



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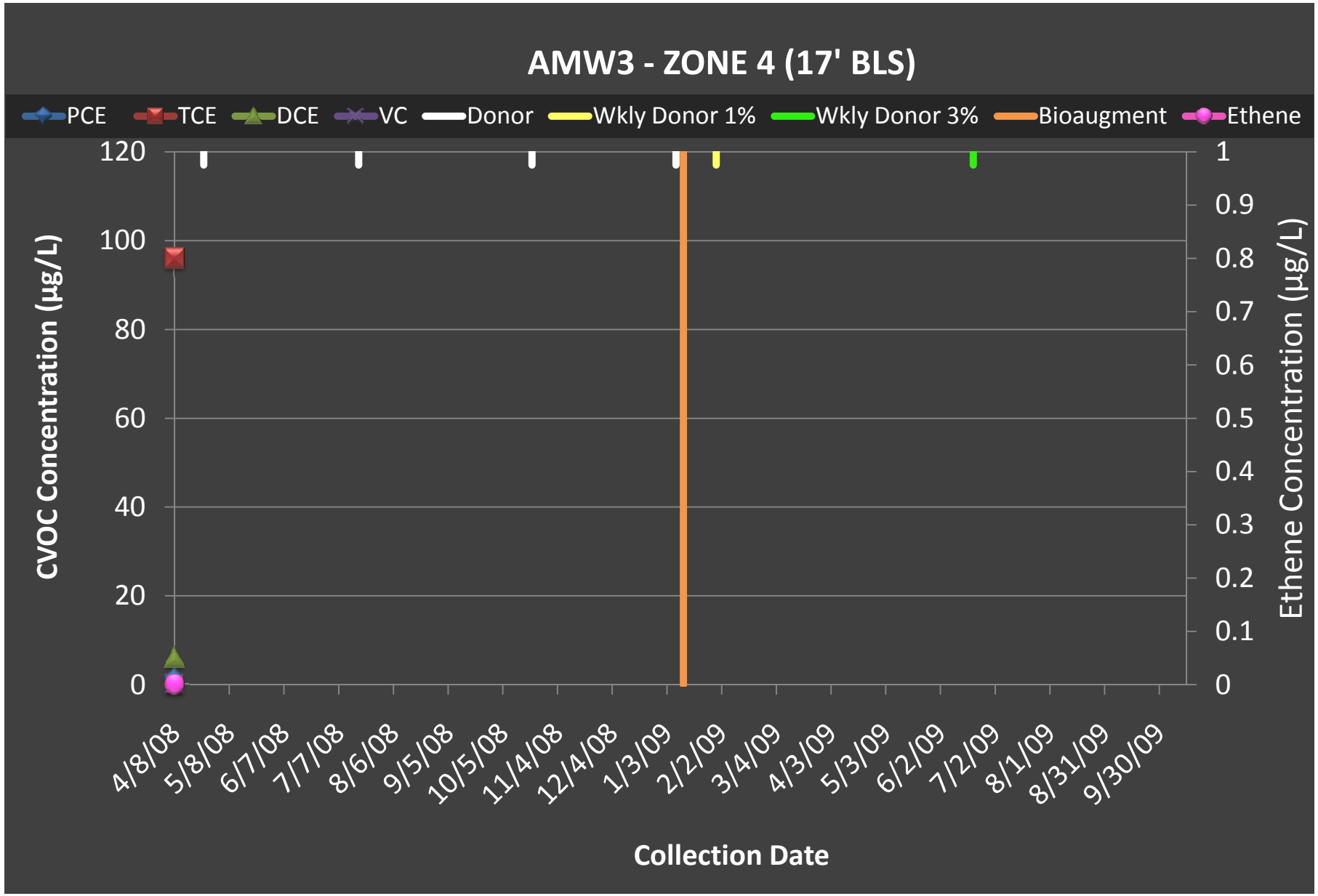
Seal Beach
Groundwater Bioaugmentation



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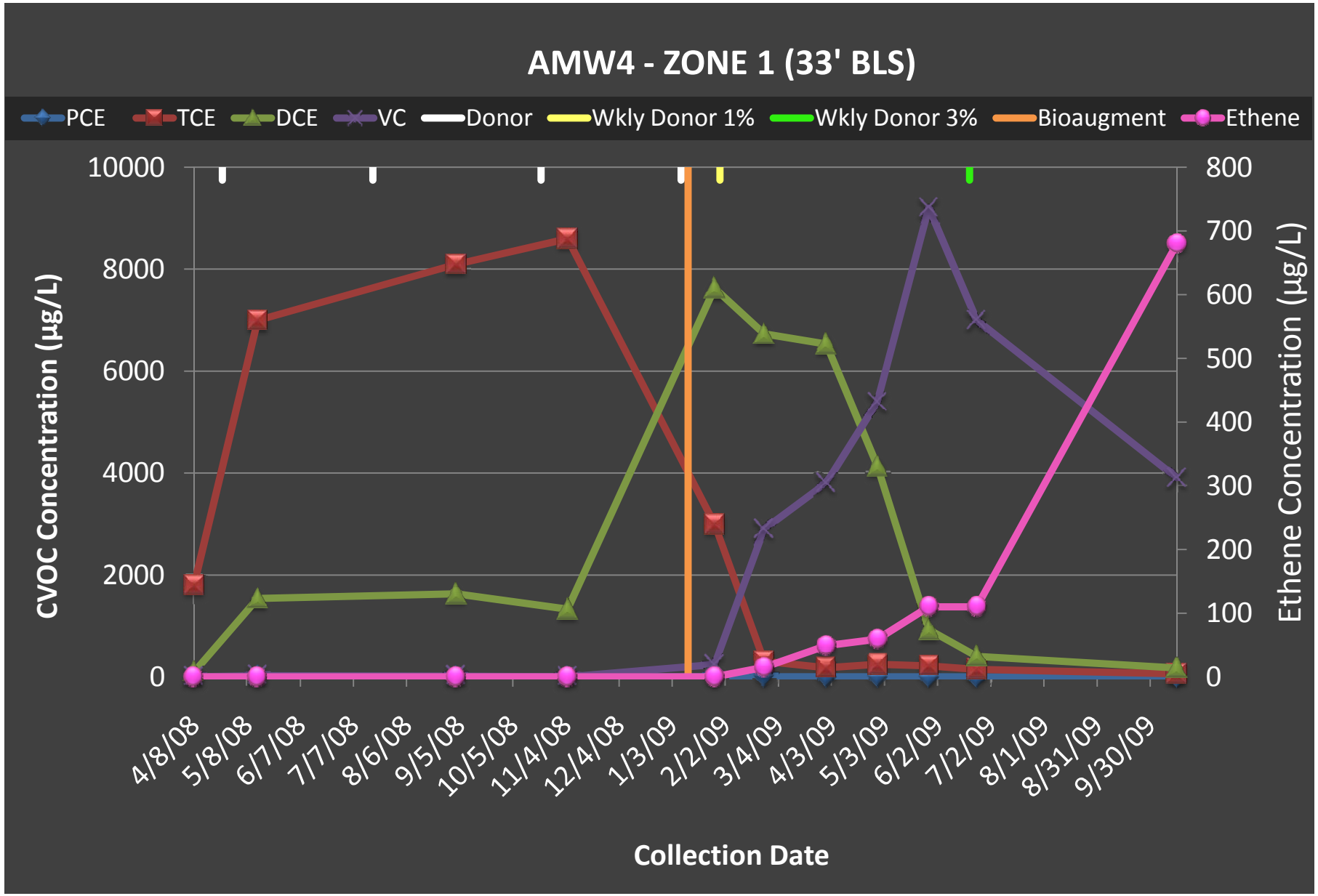
Seal Beach
Groundwater Bioaugmentation



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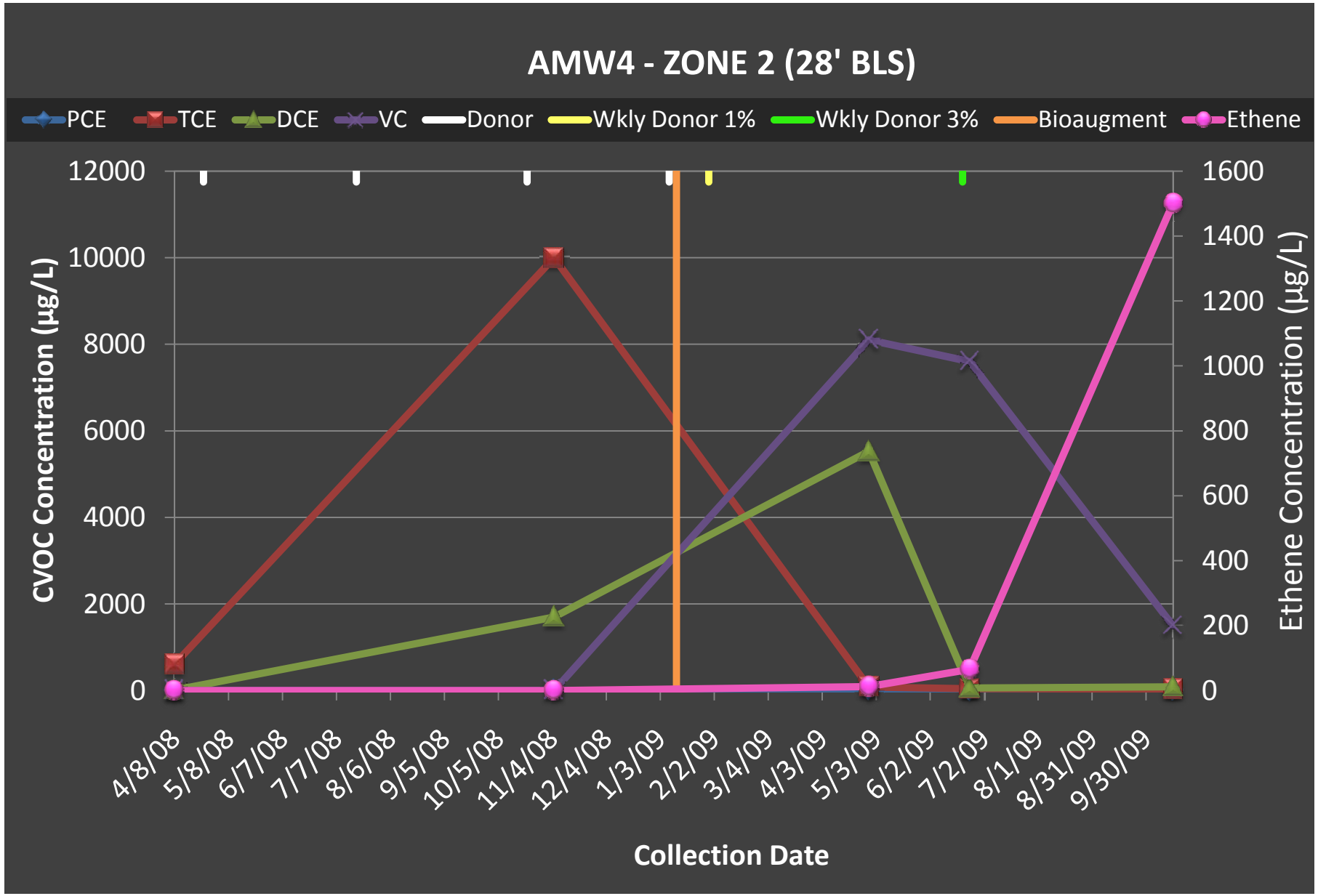
Seal Beach
Groundwater Bioaugmentation



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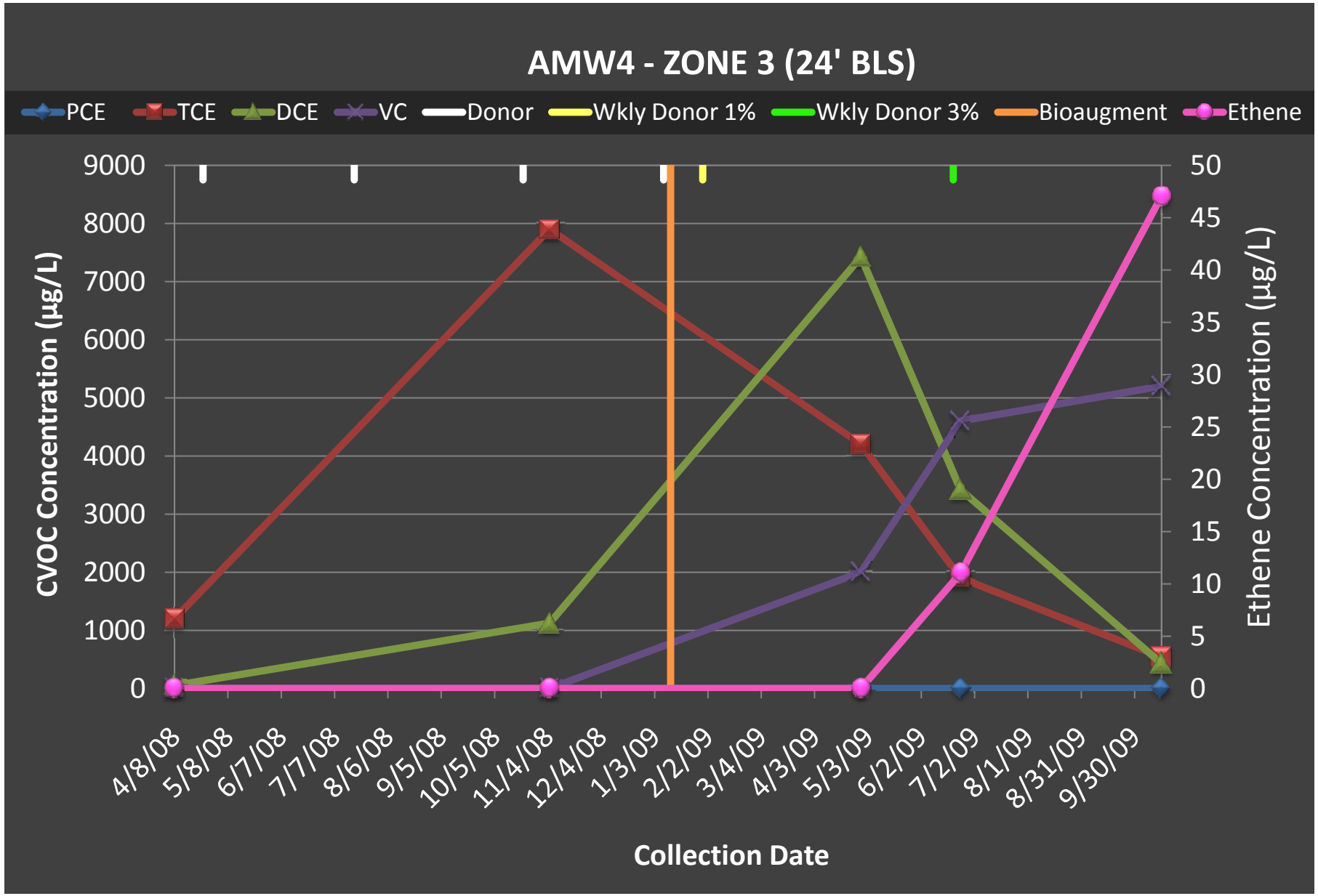
Seal Beach
Groundwater Bioaugmentation



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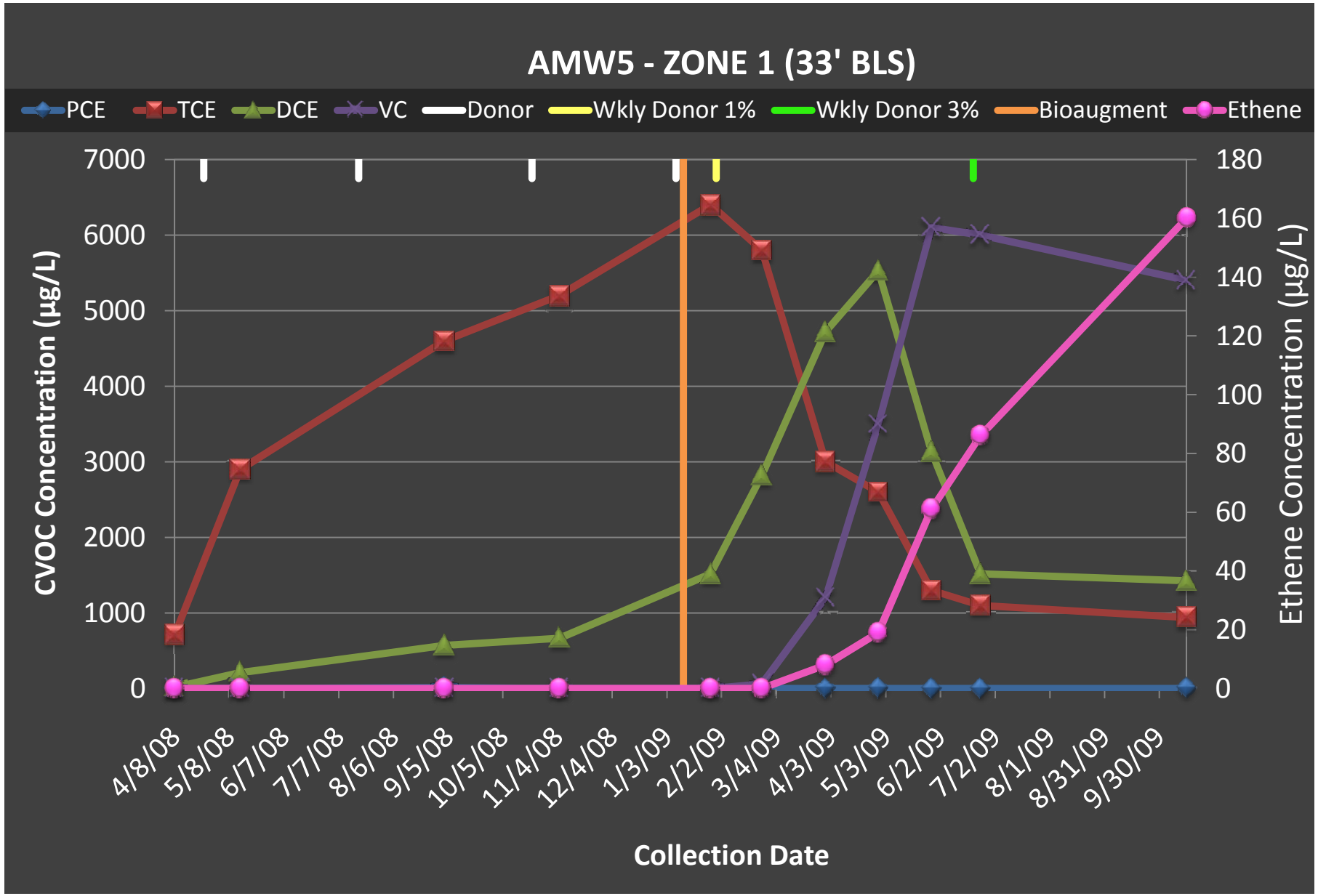
Seal Beach
Groundwater Bioaugmentation



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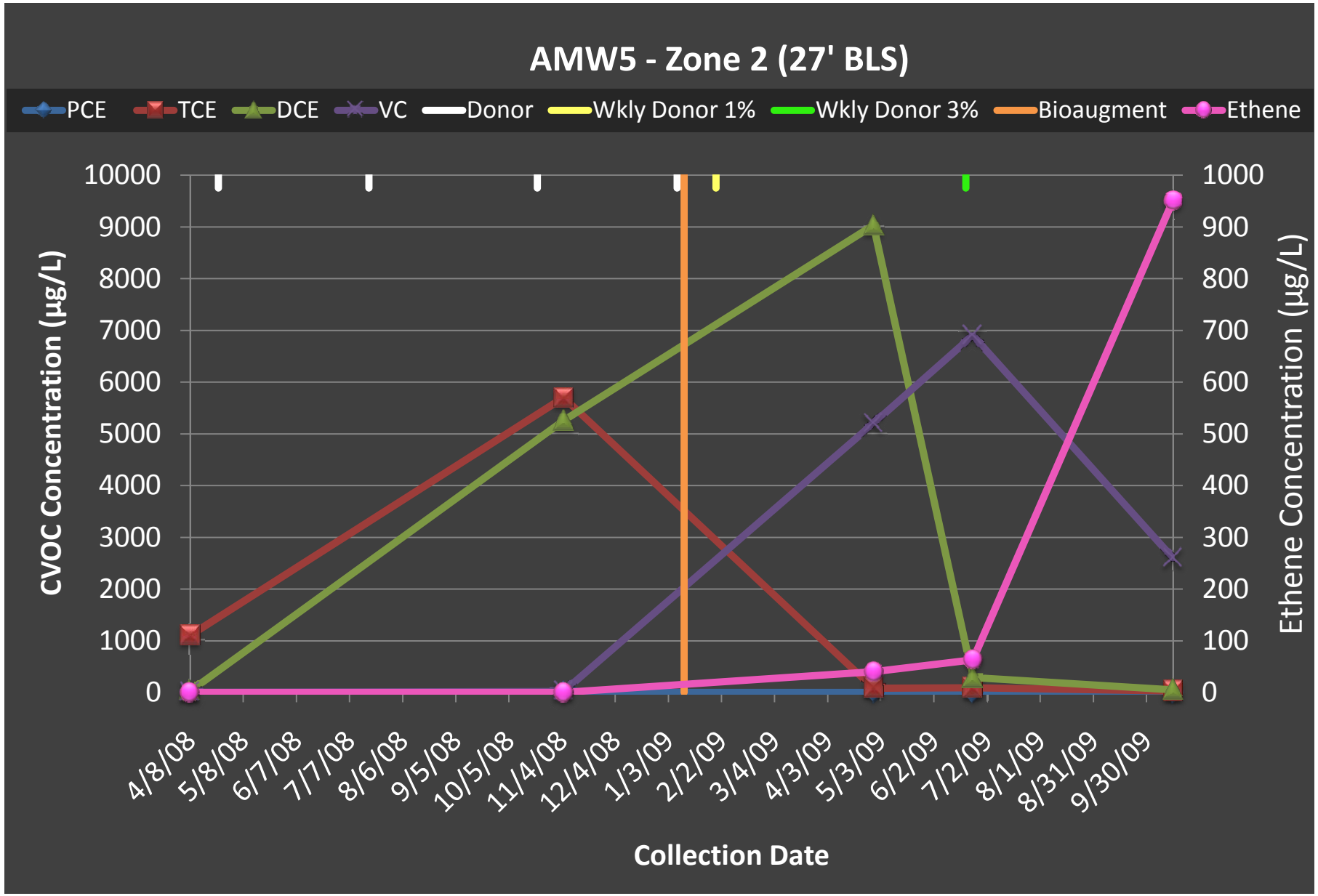
AMW5-Z1, Dechlorination_mass_Act_Seal Beach_Oct 2009.xlsx

Seal Beach
Groundwater Bioaugmentation



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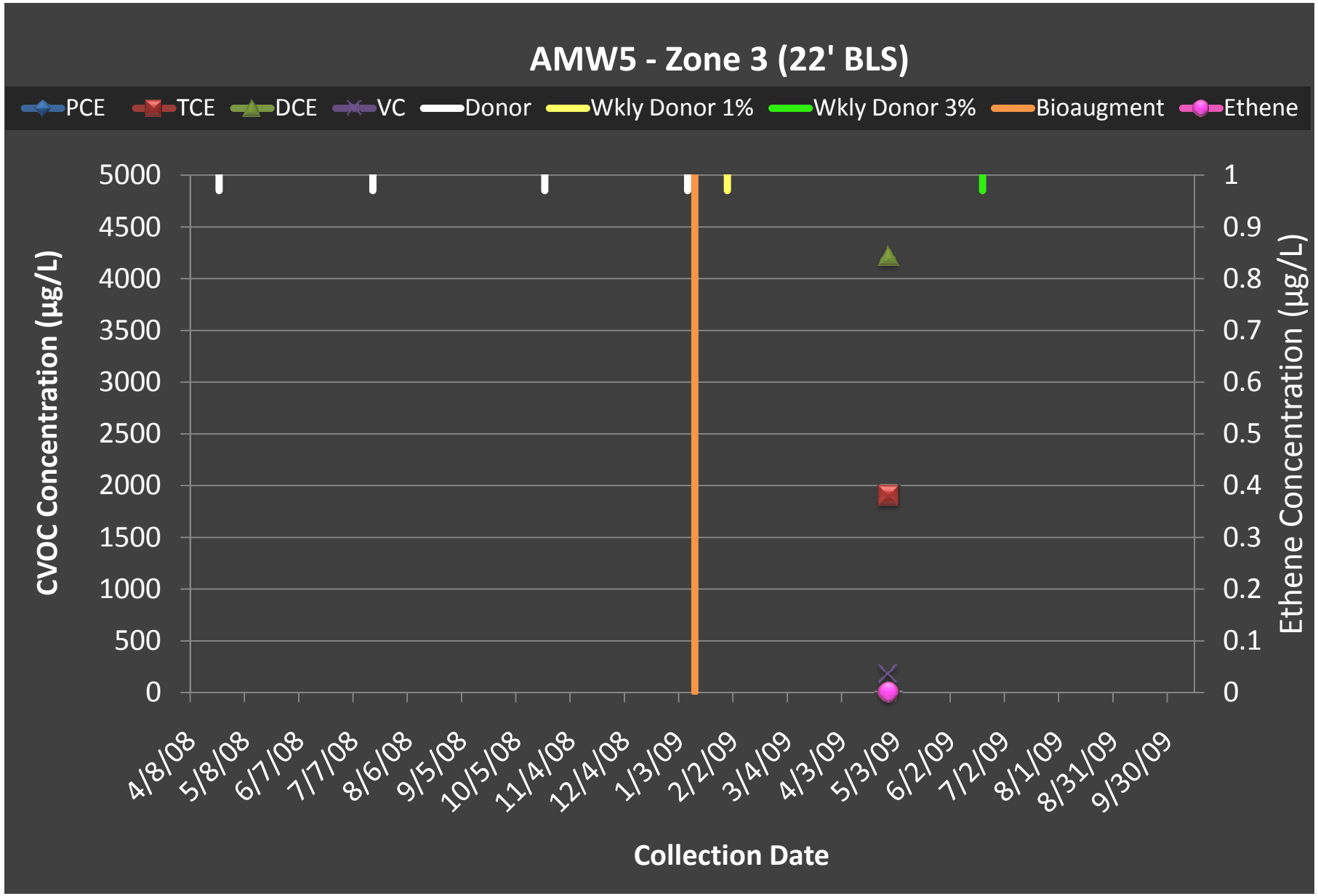
Seal Beach
Groundwater Bioaugmentation



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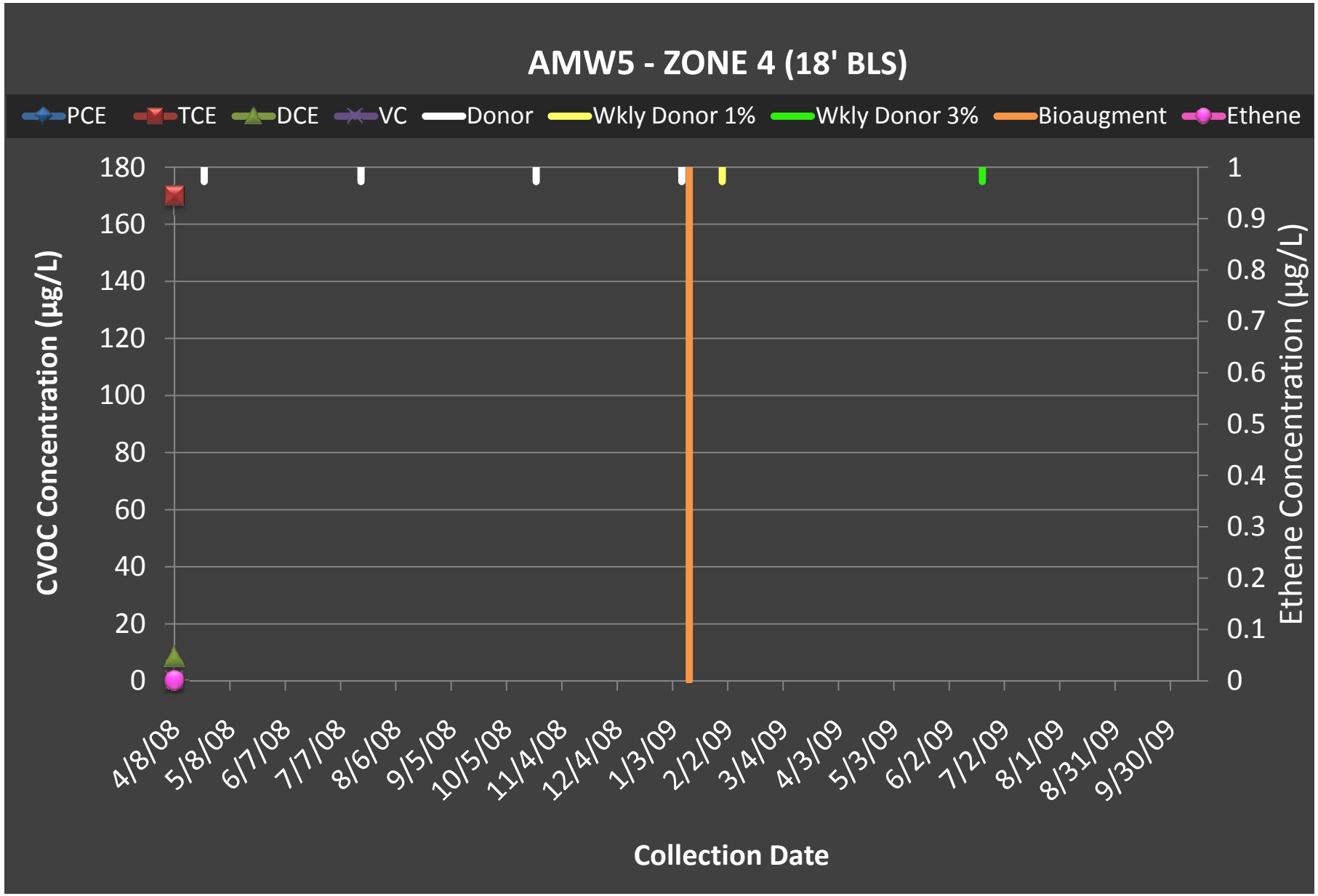
Seal Beach
Groundwater Bioaugmentation



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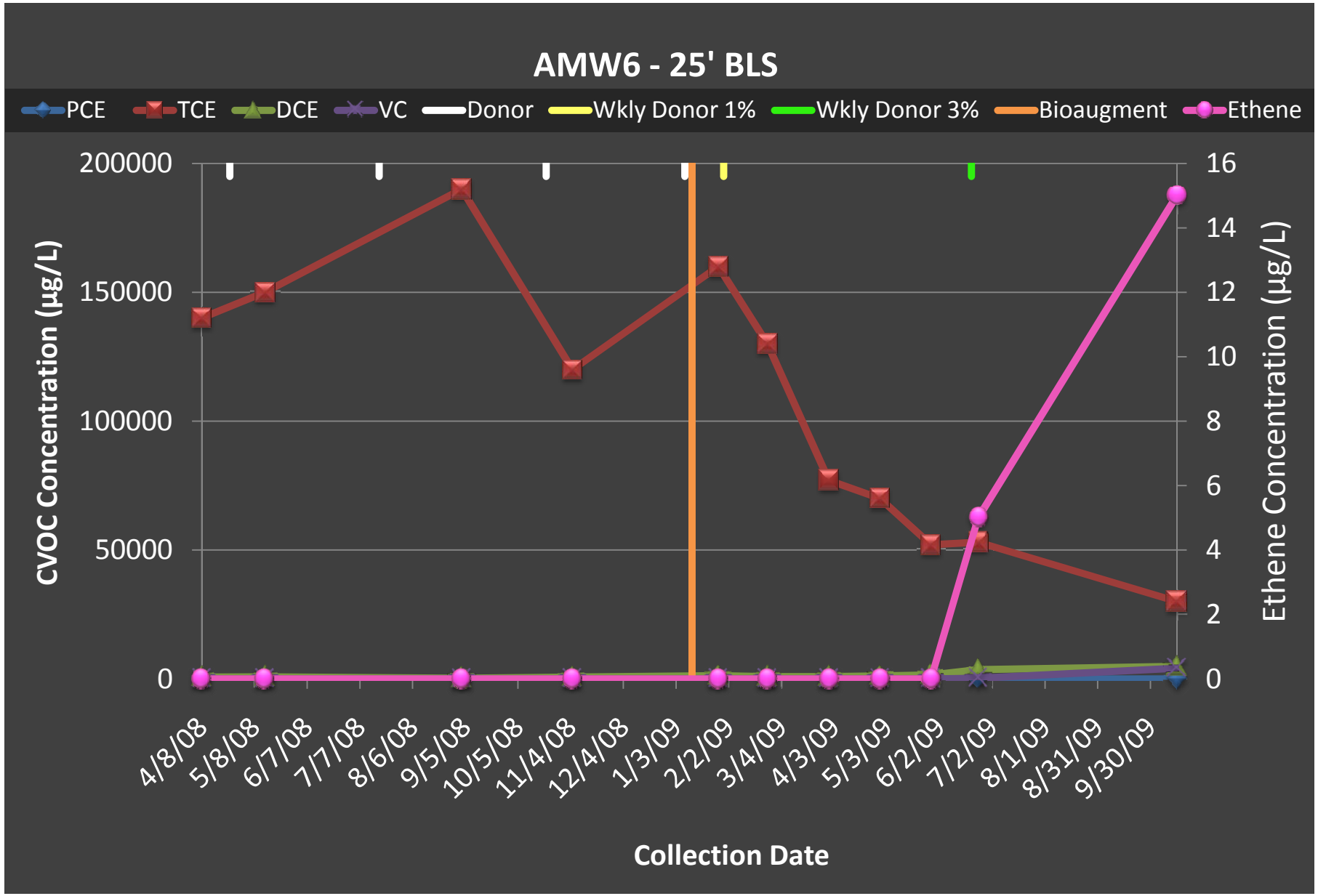
Seal Beach
Groundwater Bioaugmentation



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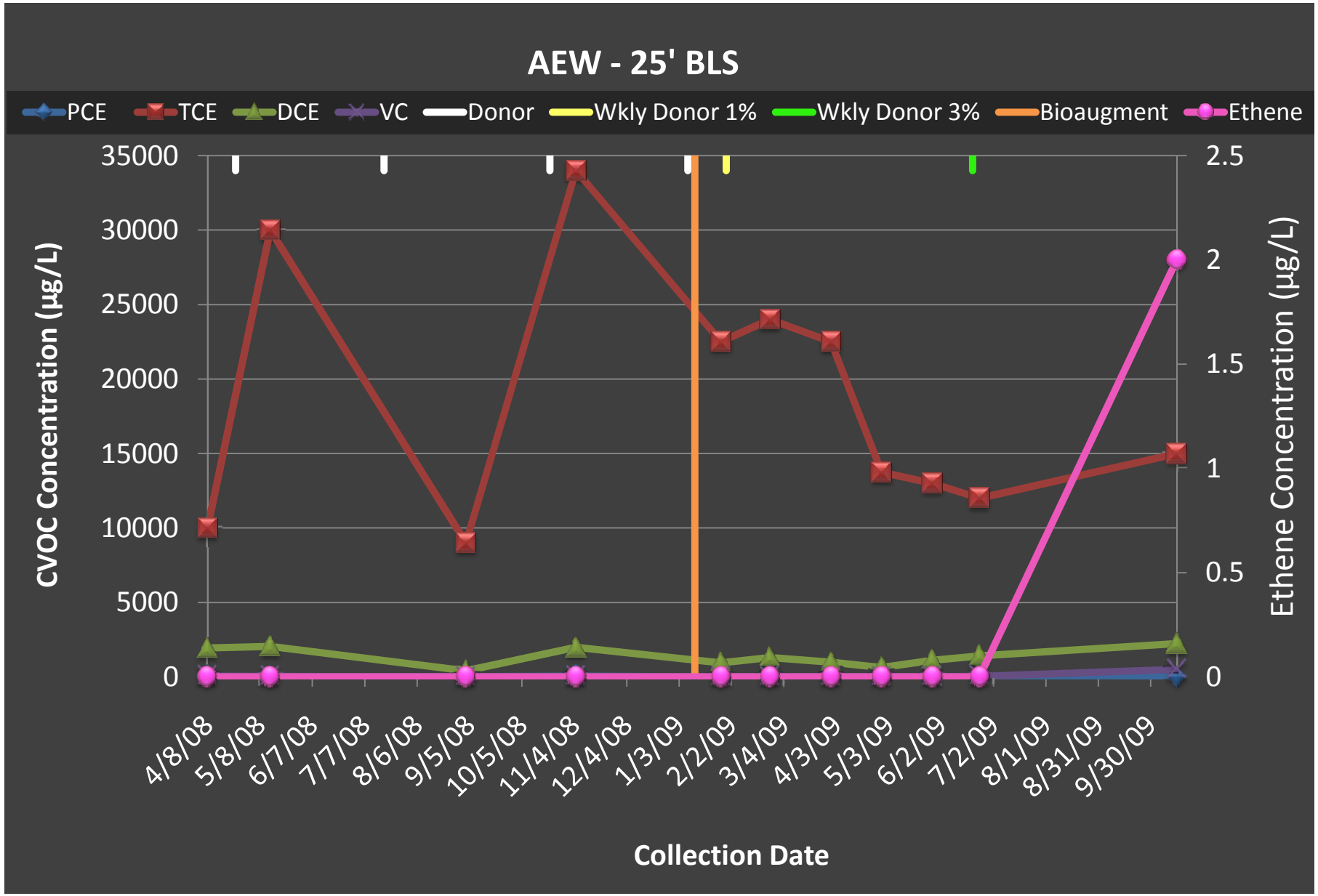
Seal Beach
Groundwater Bioaugmentation



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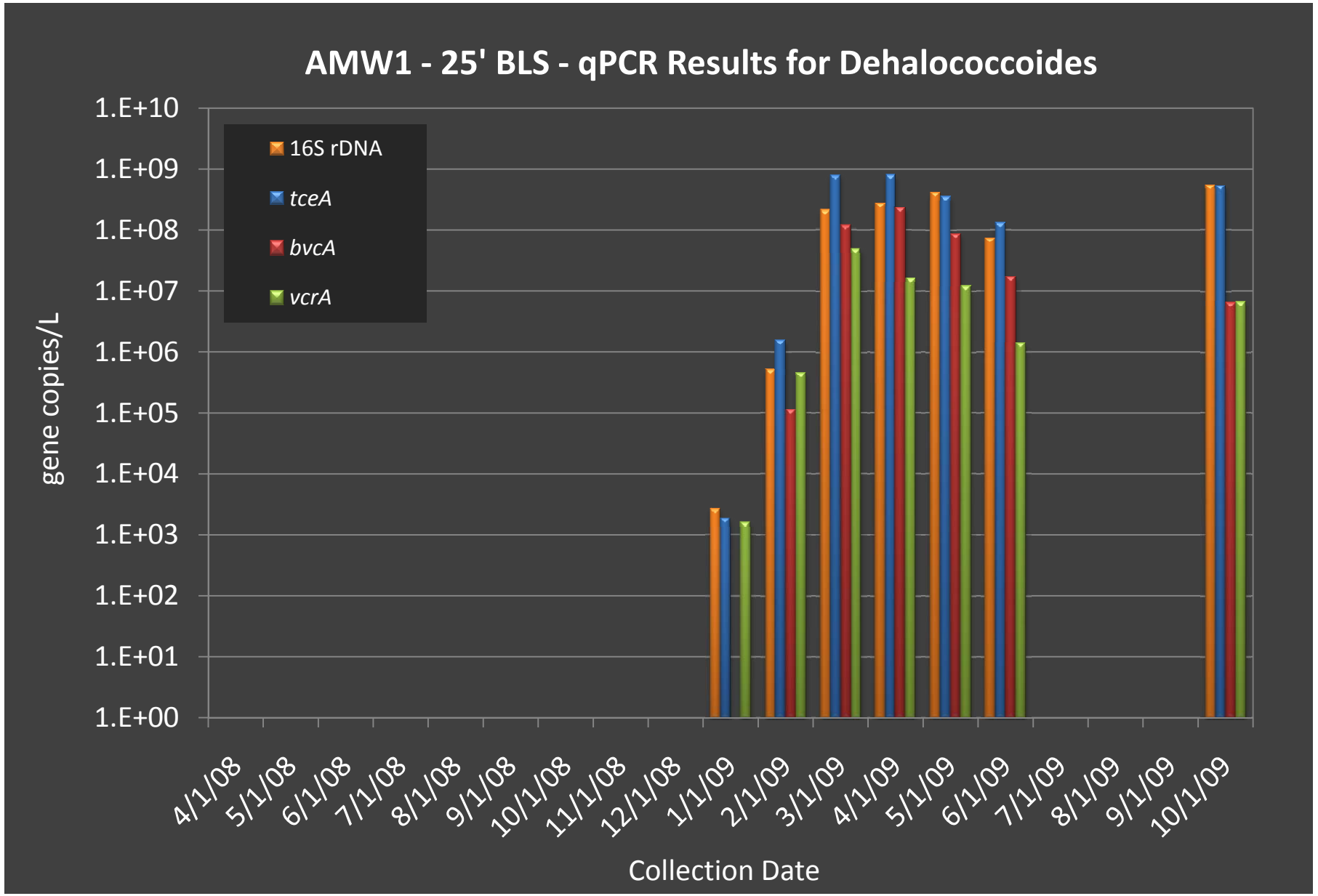
Seal Beach
Groundwater Bioaugmentation



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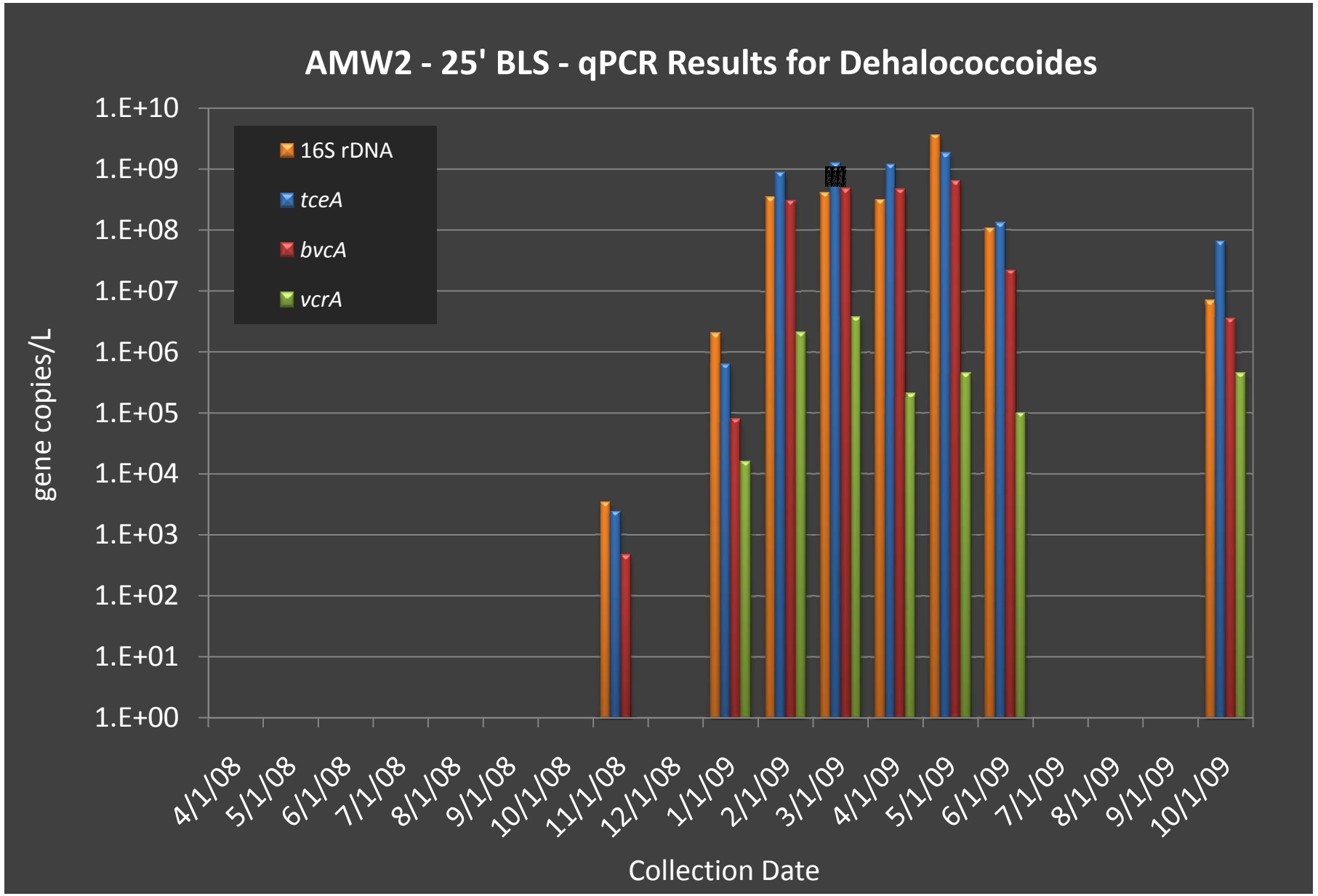
Seal Beach
Groundwater Bioaugmentation



Recirculation system was shut off between 9/2/2008 and 1/6/2009.

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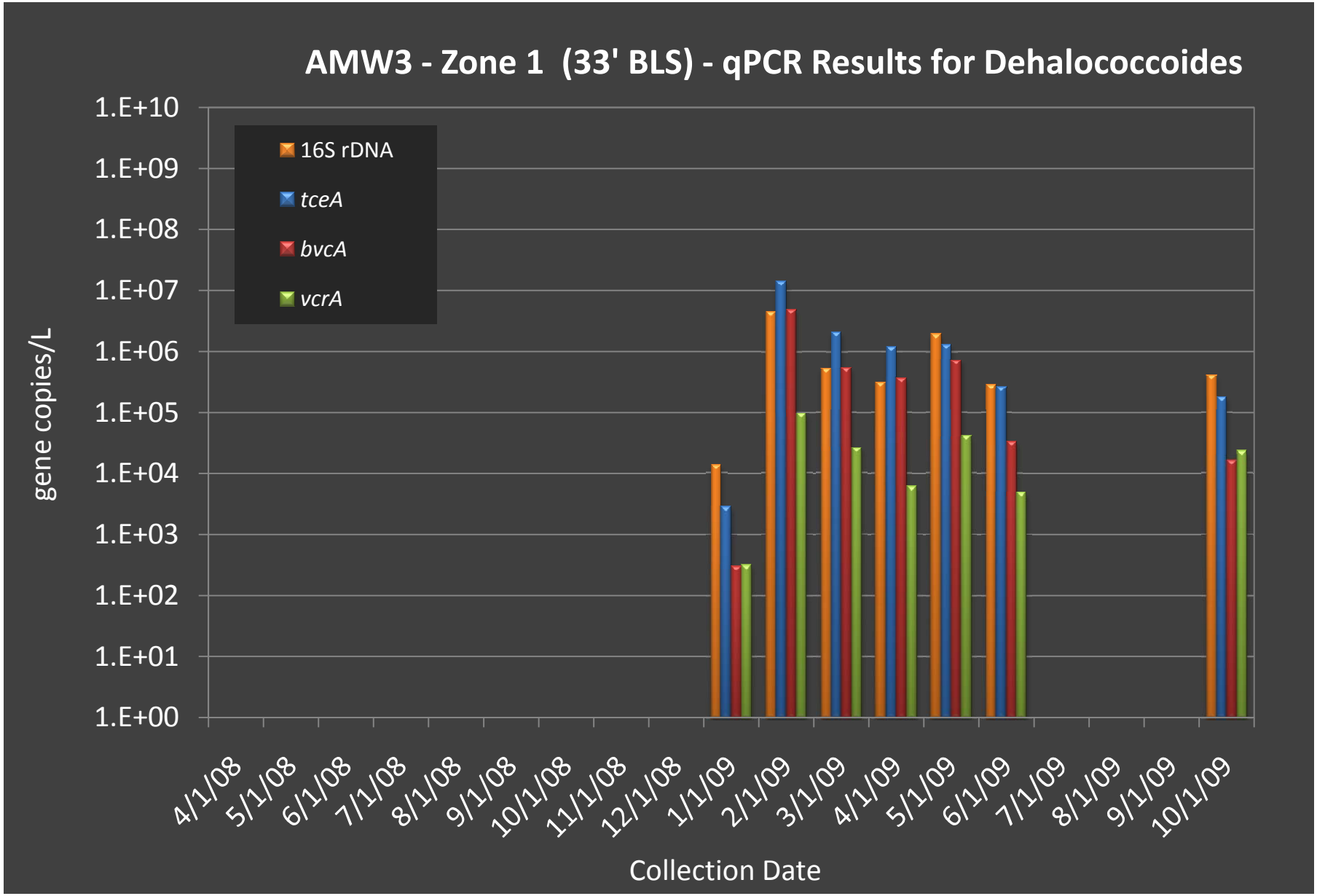
Seal Beach
Groundwater Bioaugmentation



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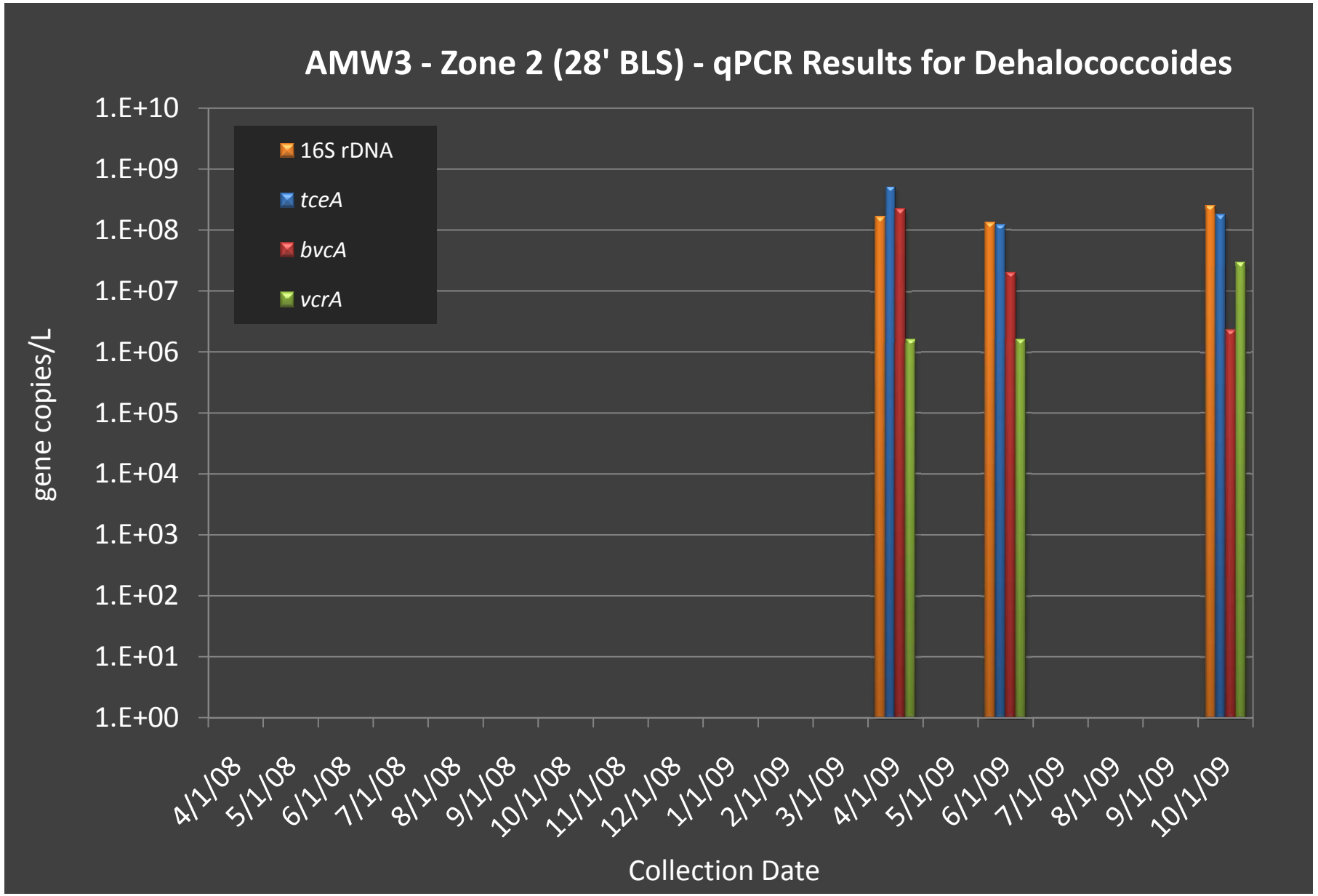
Seal Beach
Groundwater Bioaugmentation



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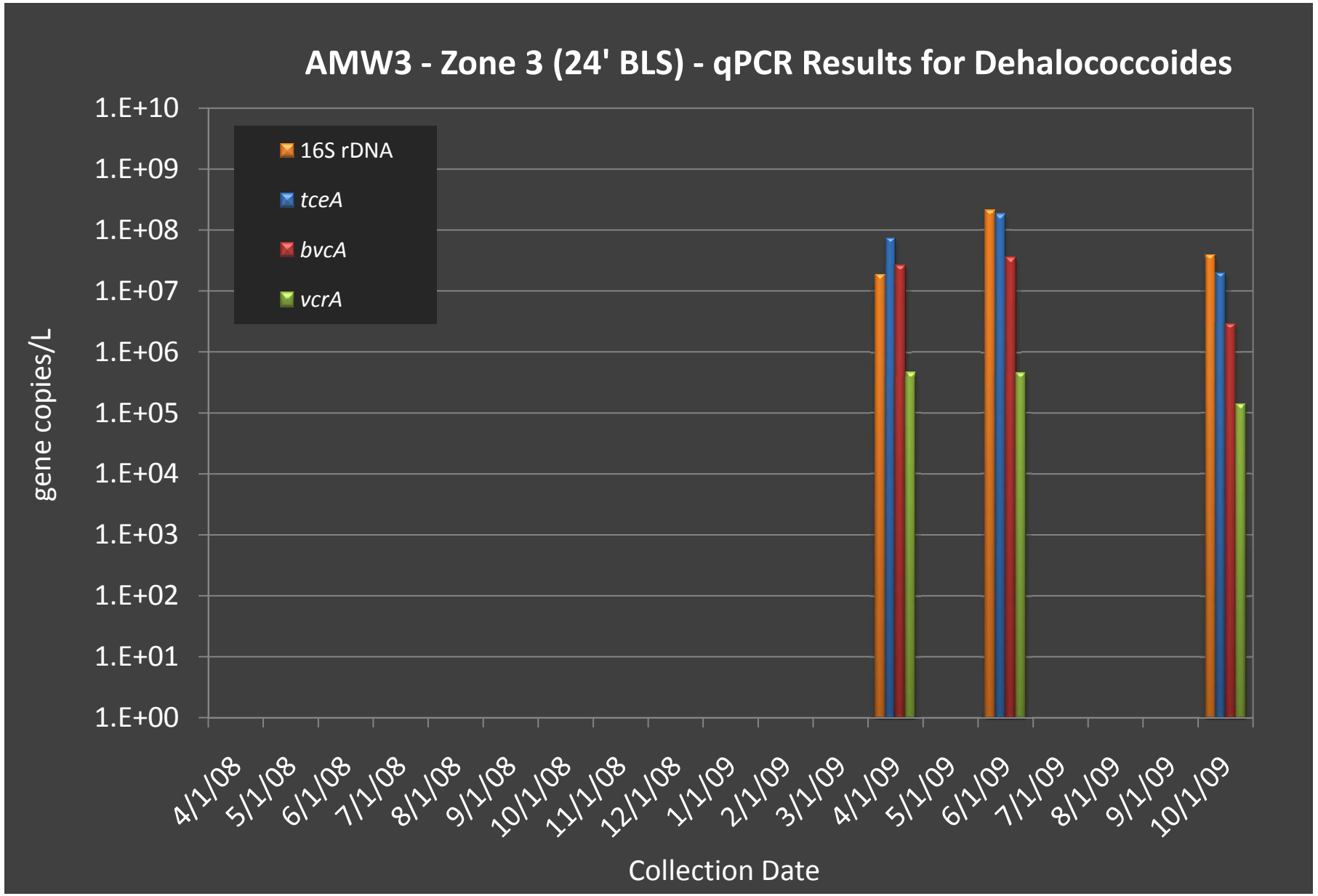
Seal Beach
Groundwater Bioaugmentation



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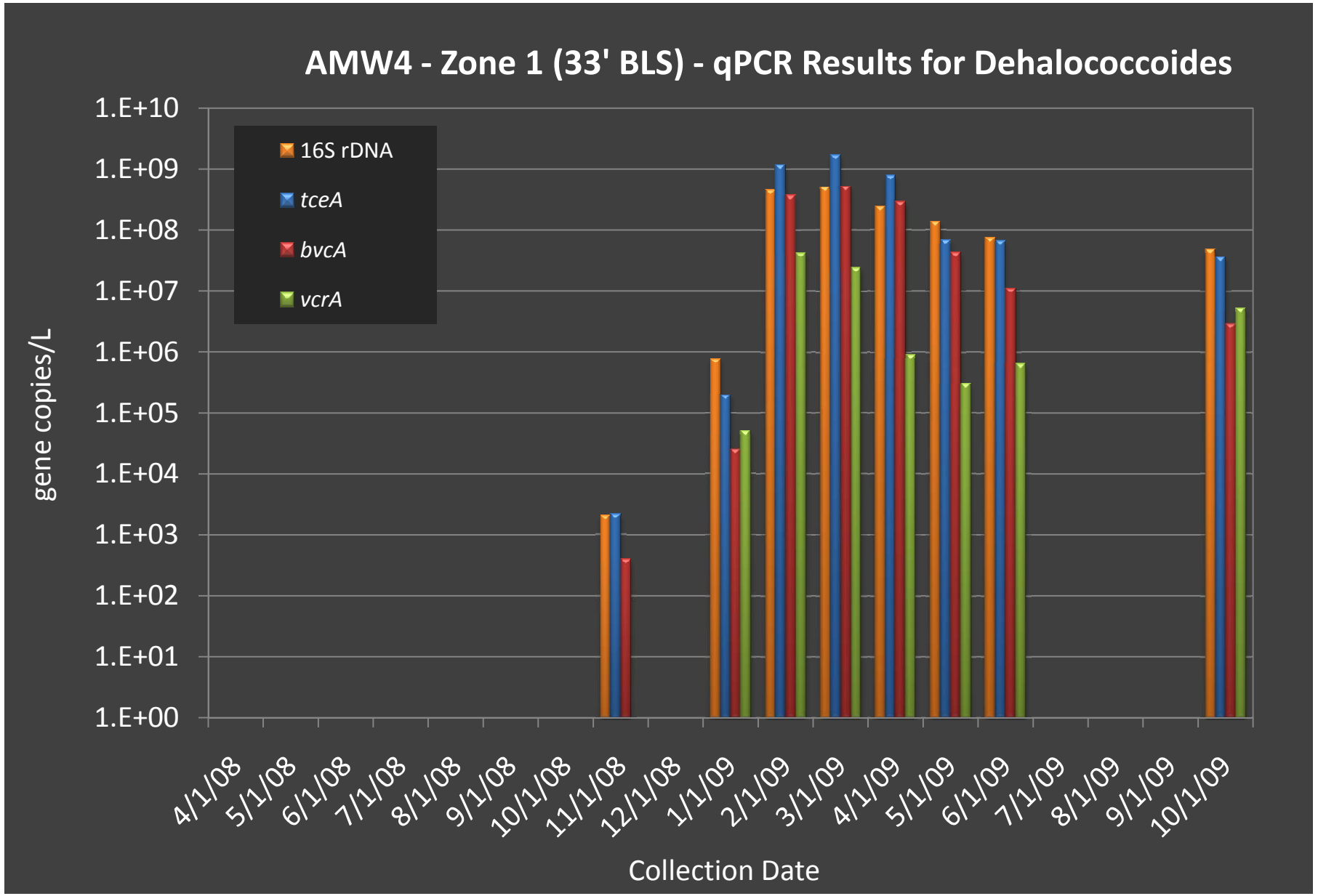
Seal Beach
Groundwater Bioaugmentation



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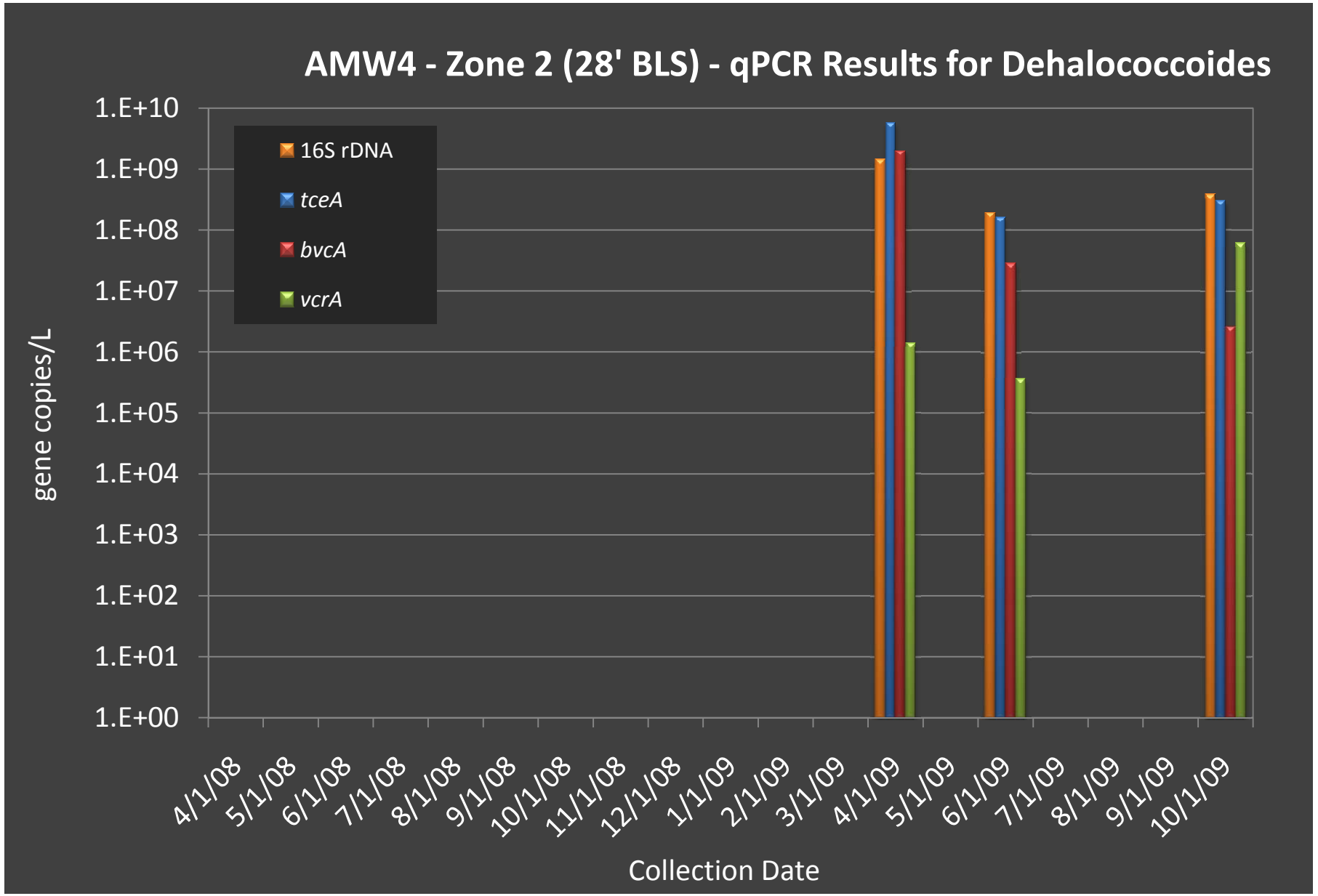
Seal Beach
Groundwater Bioaugmentation



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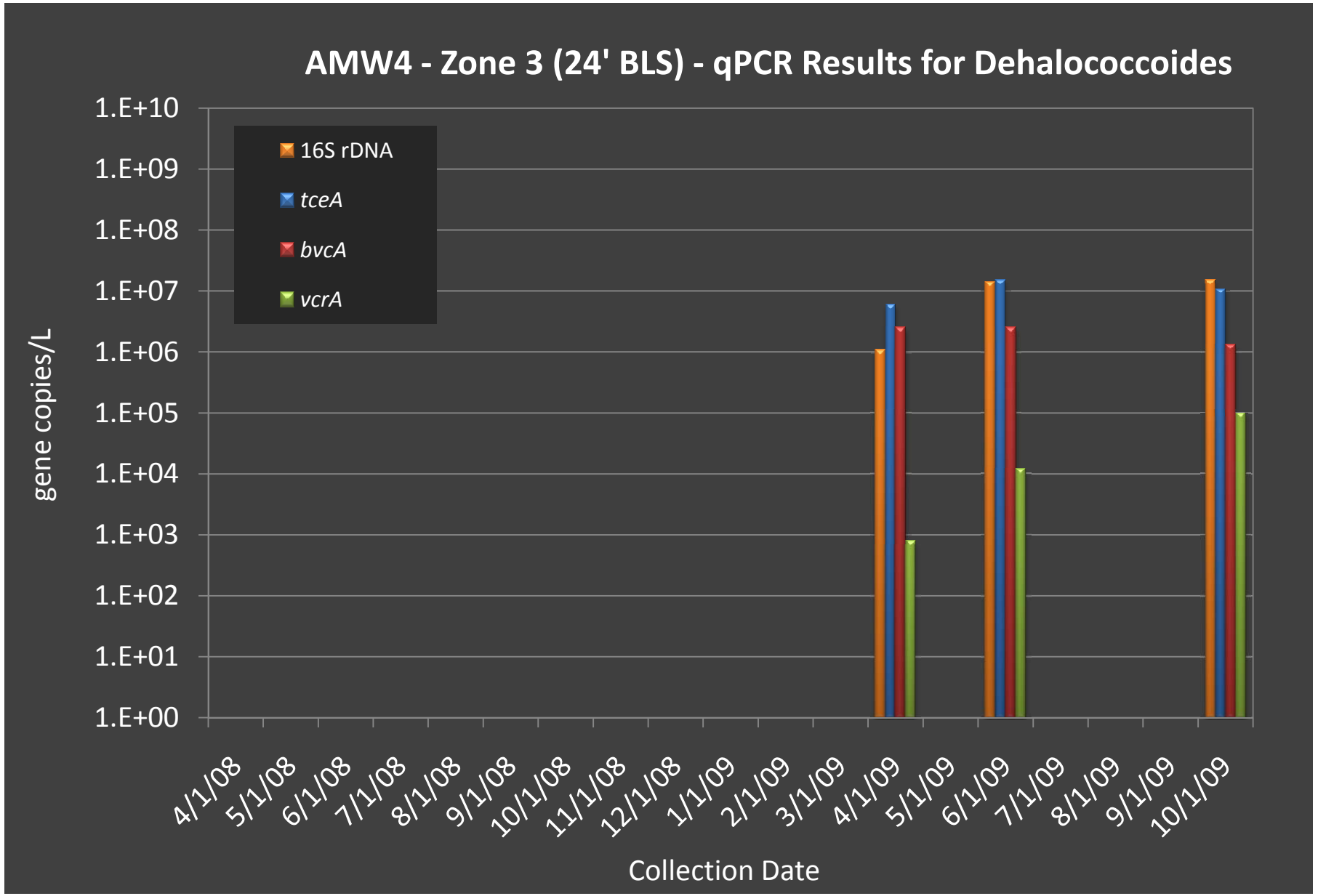
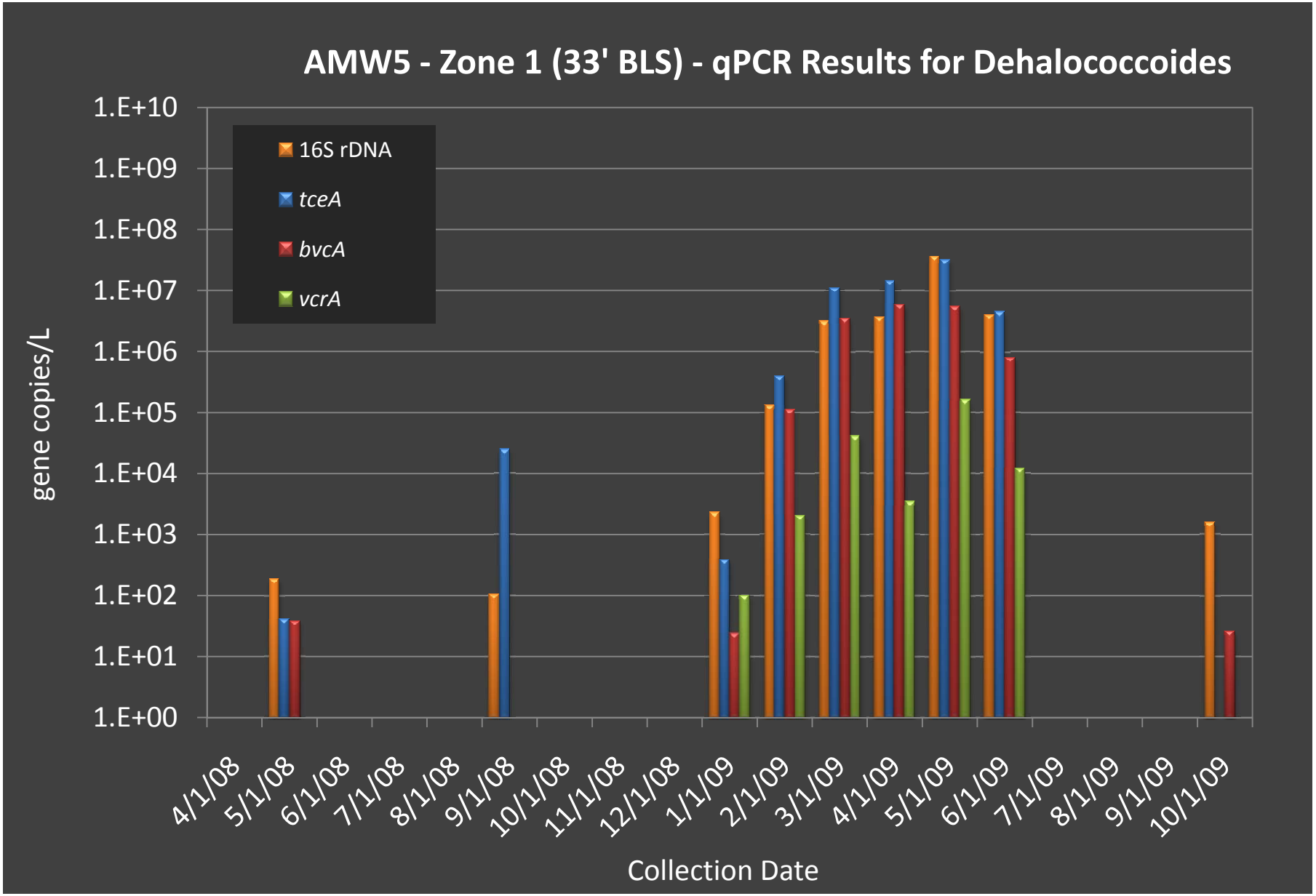
Seal Beach
Groundwater Bioaugmentation



Recirculation system was shut off between 9/2/2008 and 1/6/2009.

Seal Beach
Groundwater Bioaugmentation



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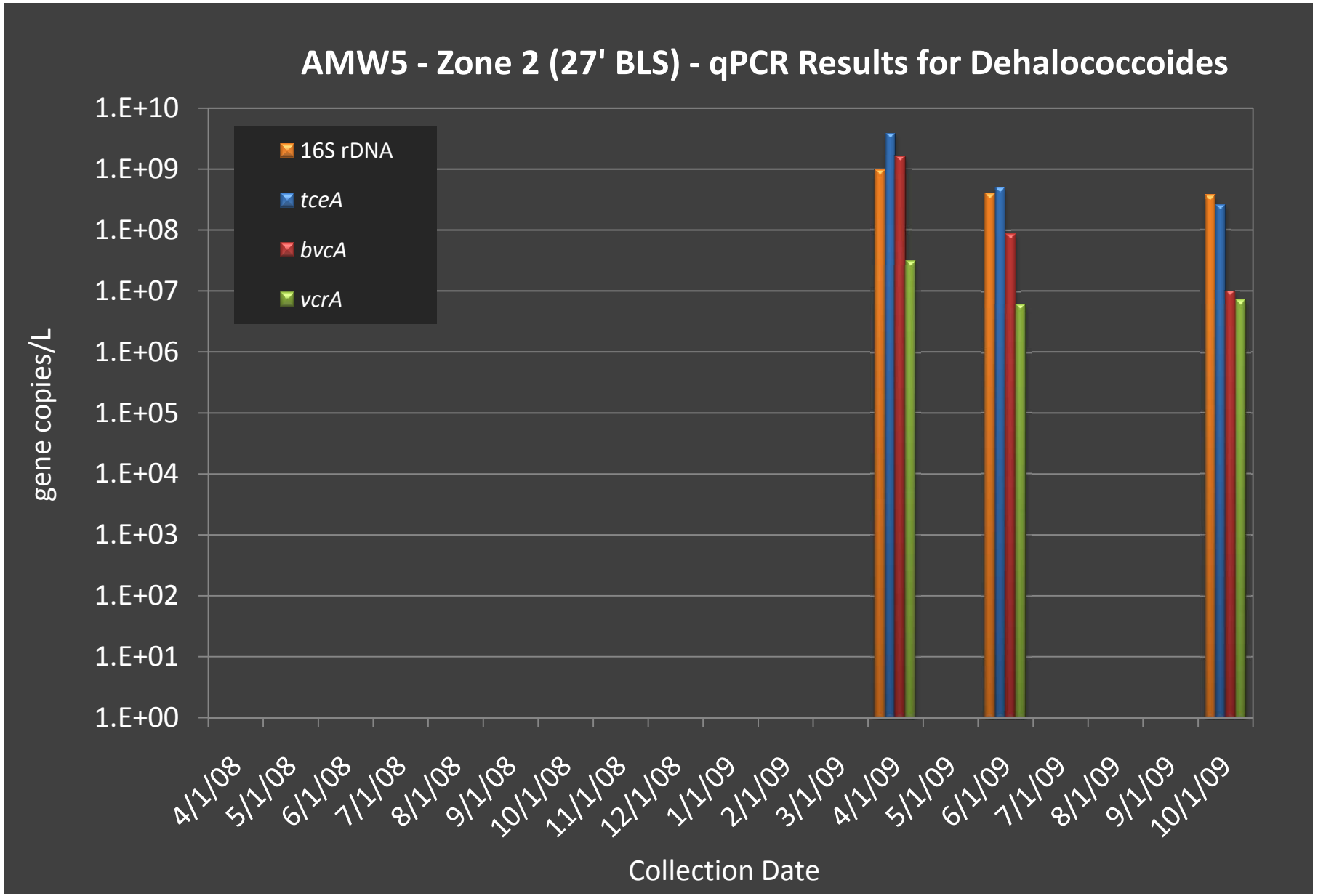
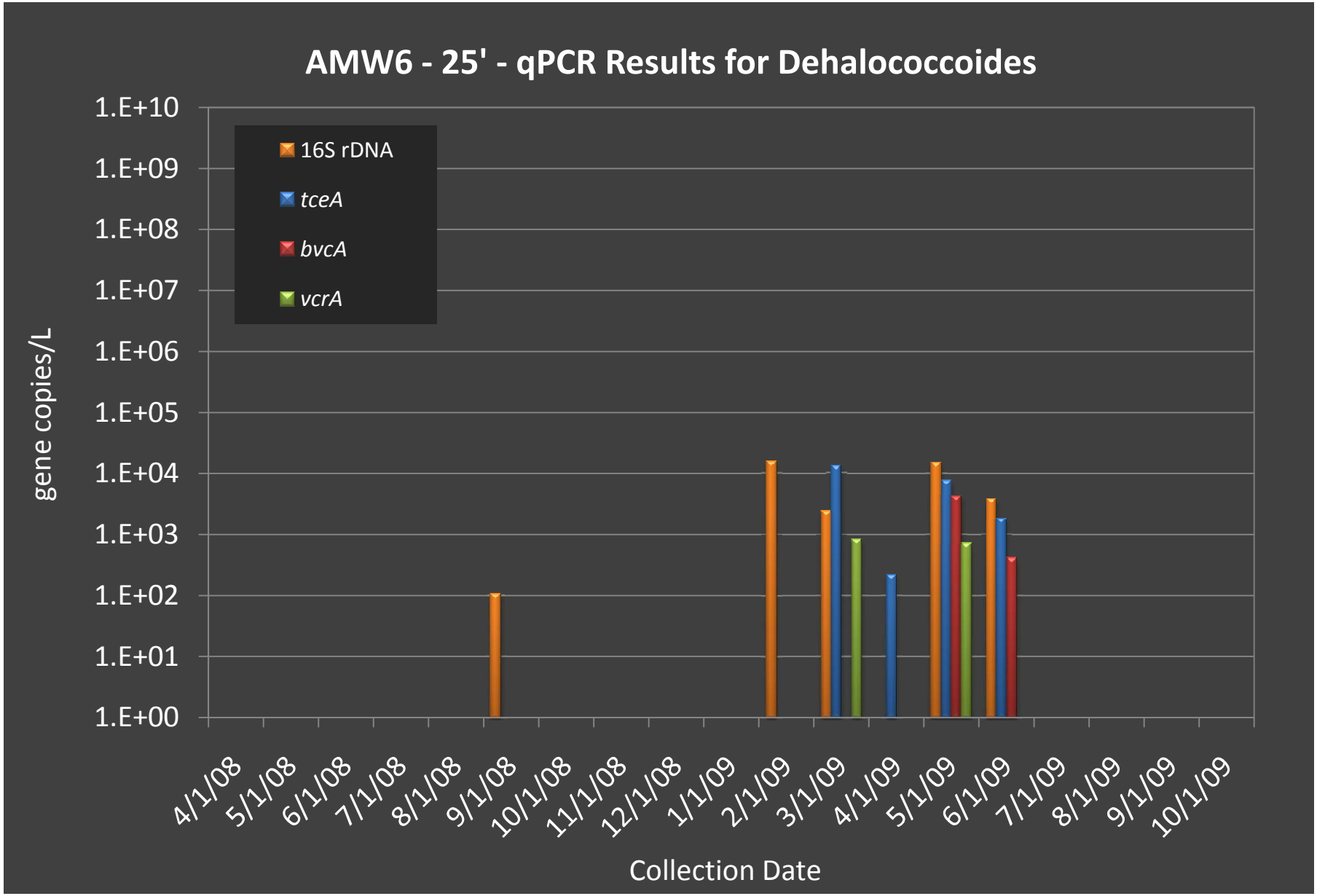
Seal Beach
Groundwater Bioaugmentation



Recirculation system was shut off between 9/2/2008 and 1/6/2009.

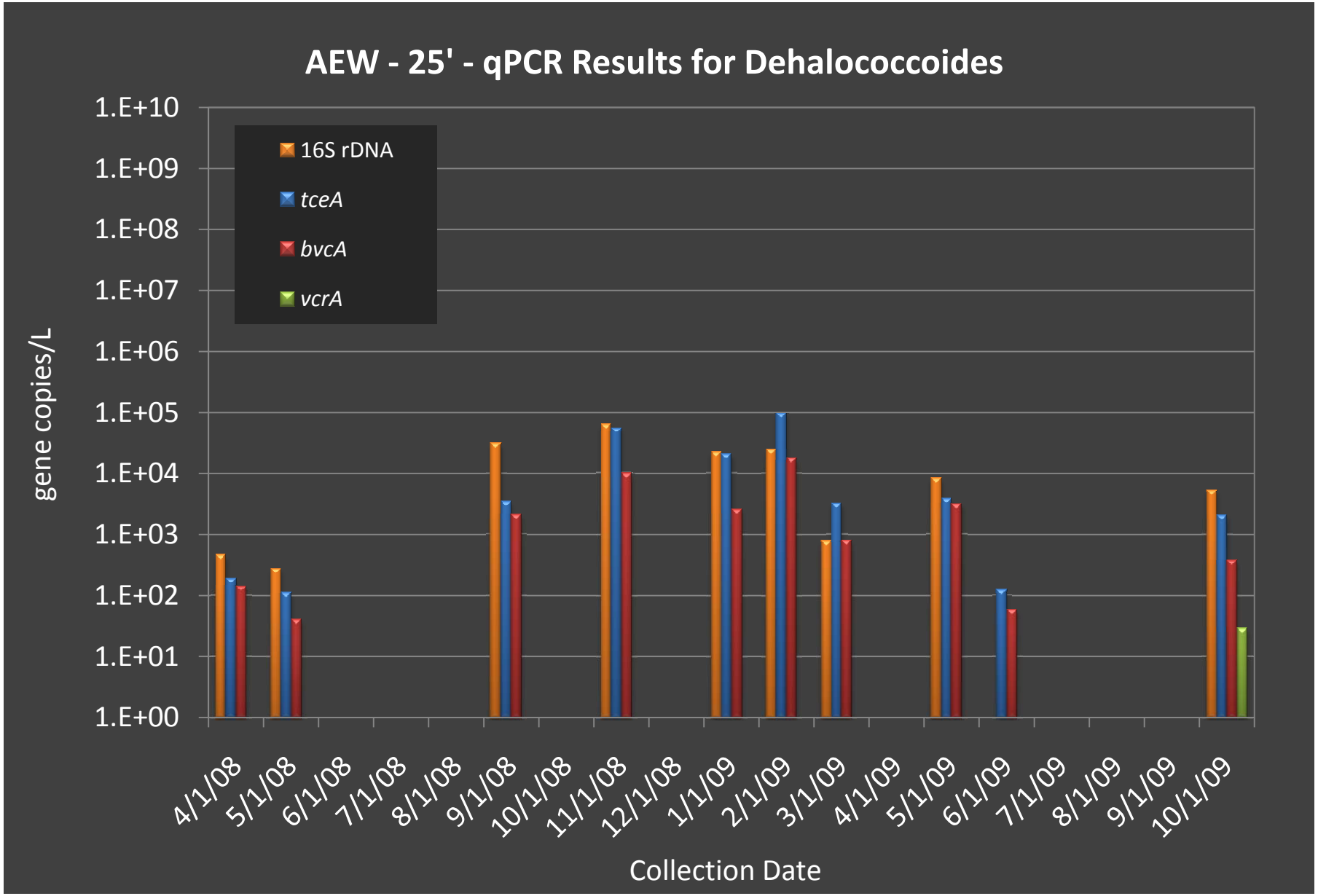
Seal Beach
Groundwater Bioaugmentation



Recirculation system was shut off between 9/2/2008 and 1/6/2009.

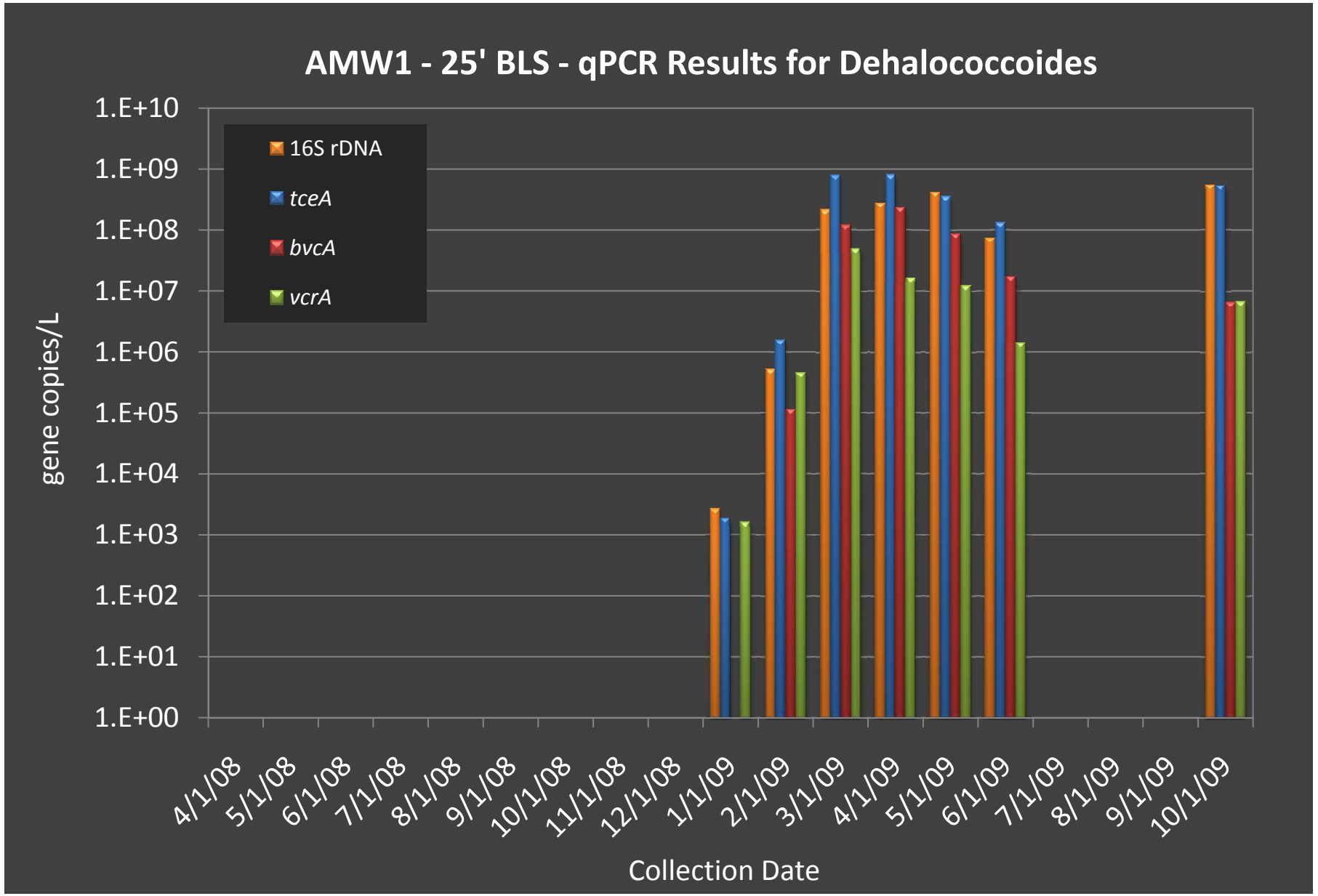
AMW6-25, DHC_Act_Seal Beach_Oct 2009.xls

Seal Beach
Groundwater Bioaugmentation



Recirculation system was shut off between 9/2/2008 and 1/6/2009.

Seal Beach
Groundwater Bioaugmentation



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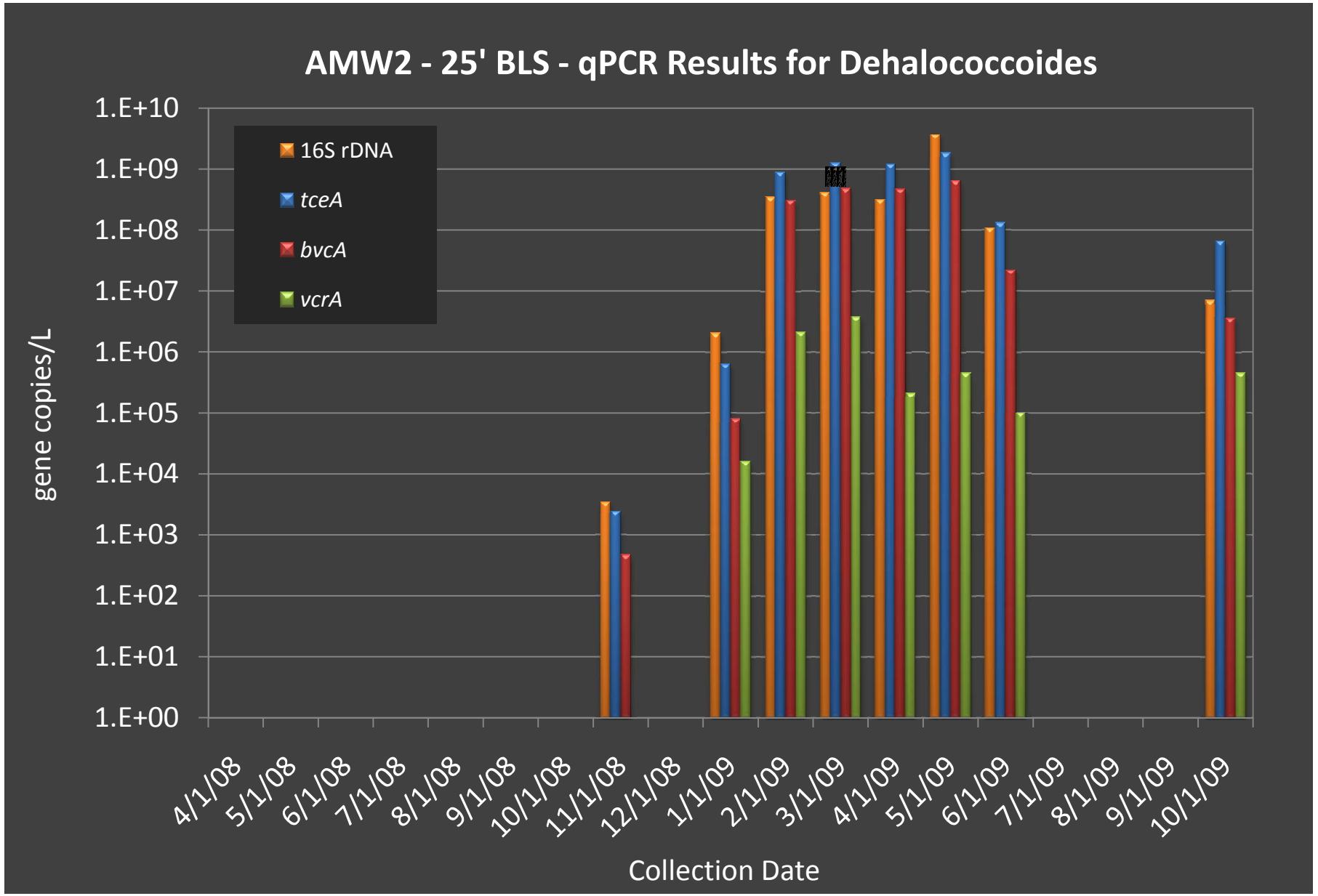
Seal Beach
Groundwater Bioaugmentation



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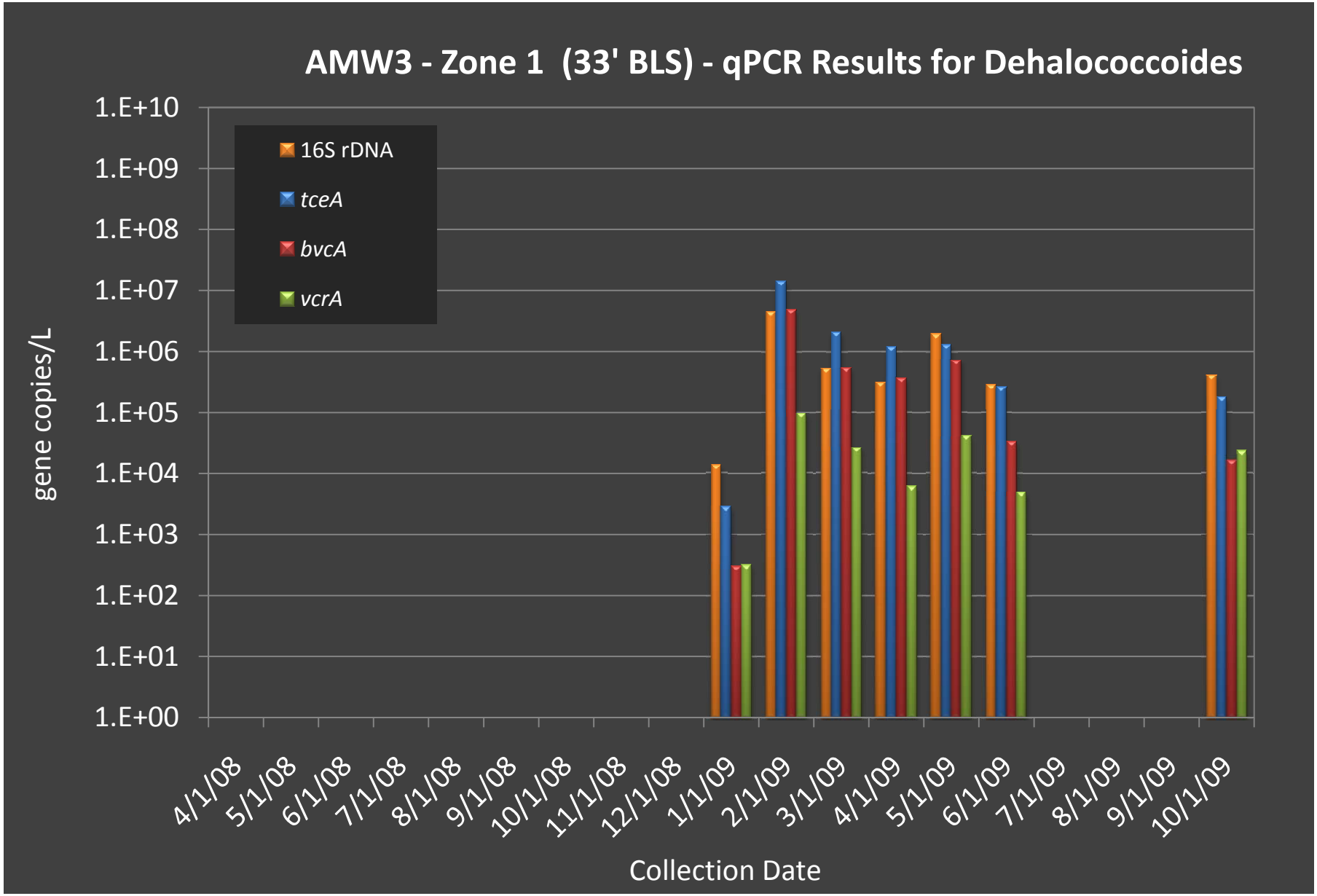
AMW2-25, DHC_Act_Seal Beach_Oct 2009.xls

Seal Beach
Groundwater Bioaugmentation



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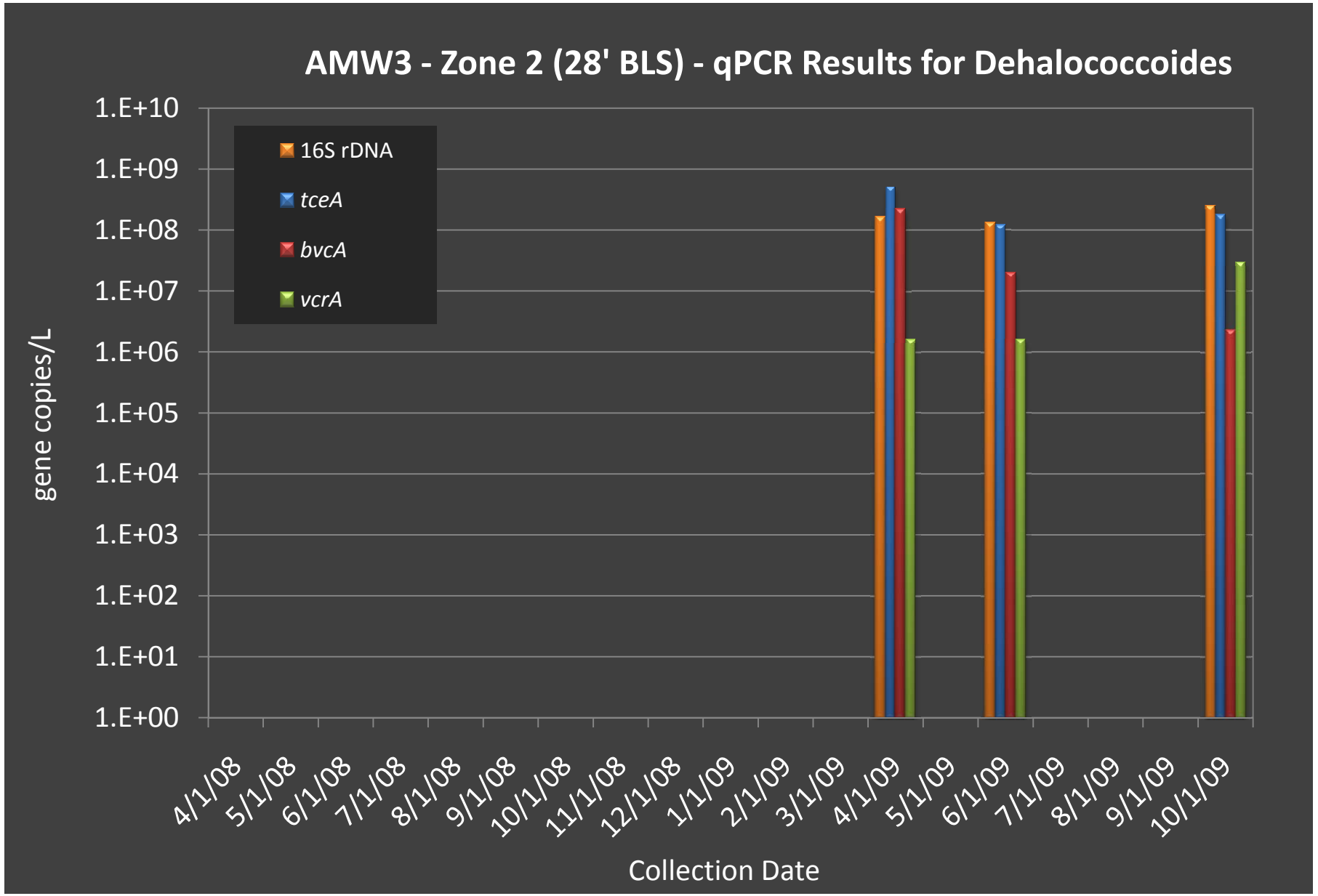
Seal Beach
Groundwater Bioaugmentation



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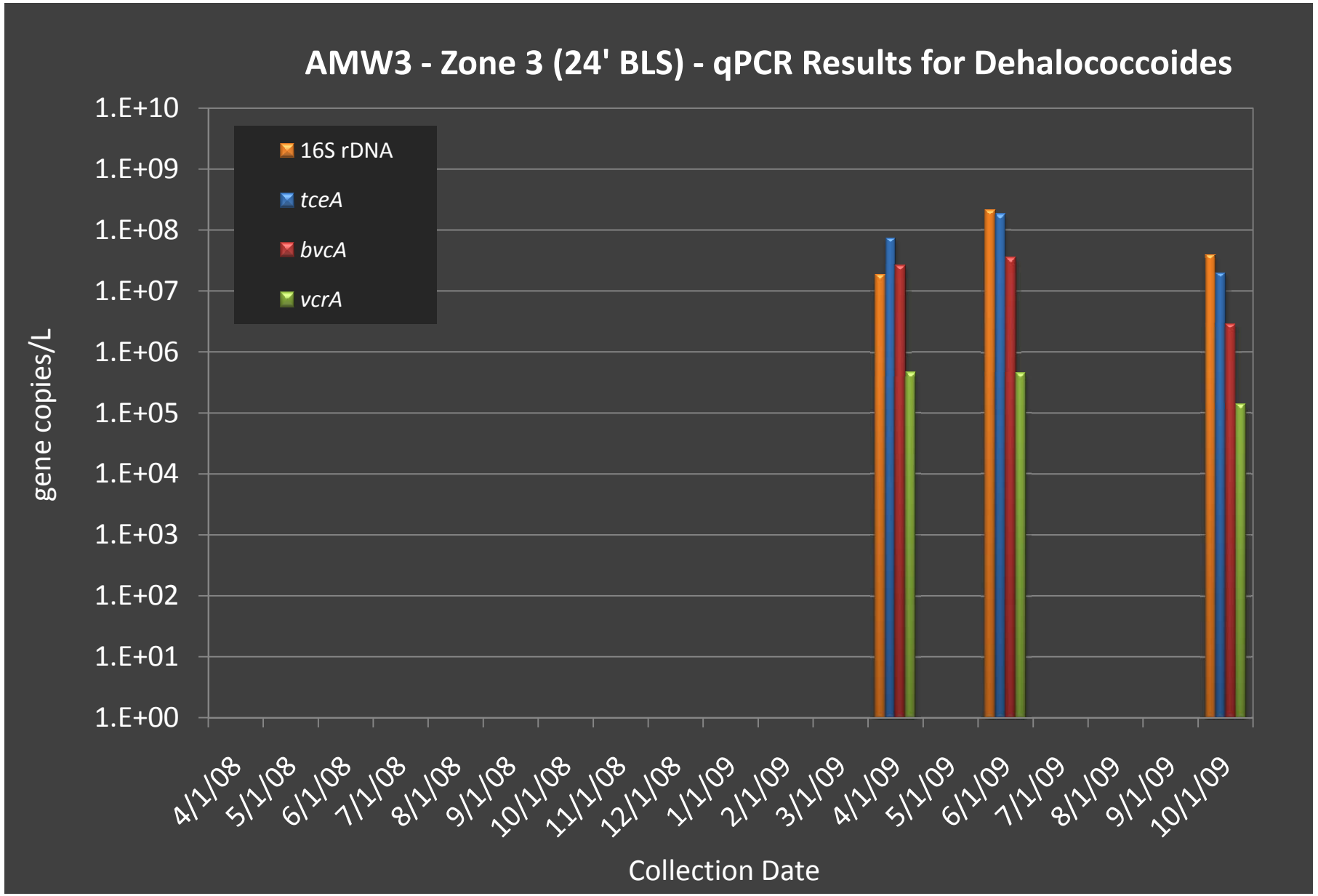
Seal Beach
Groundwater Bioaugmentation



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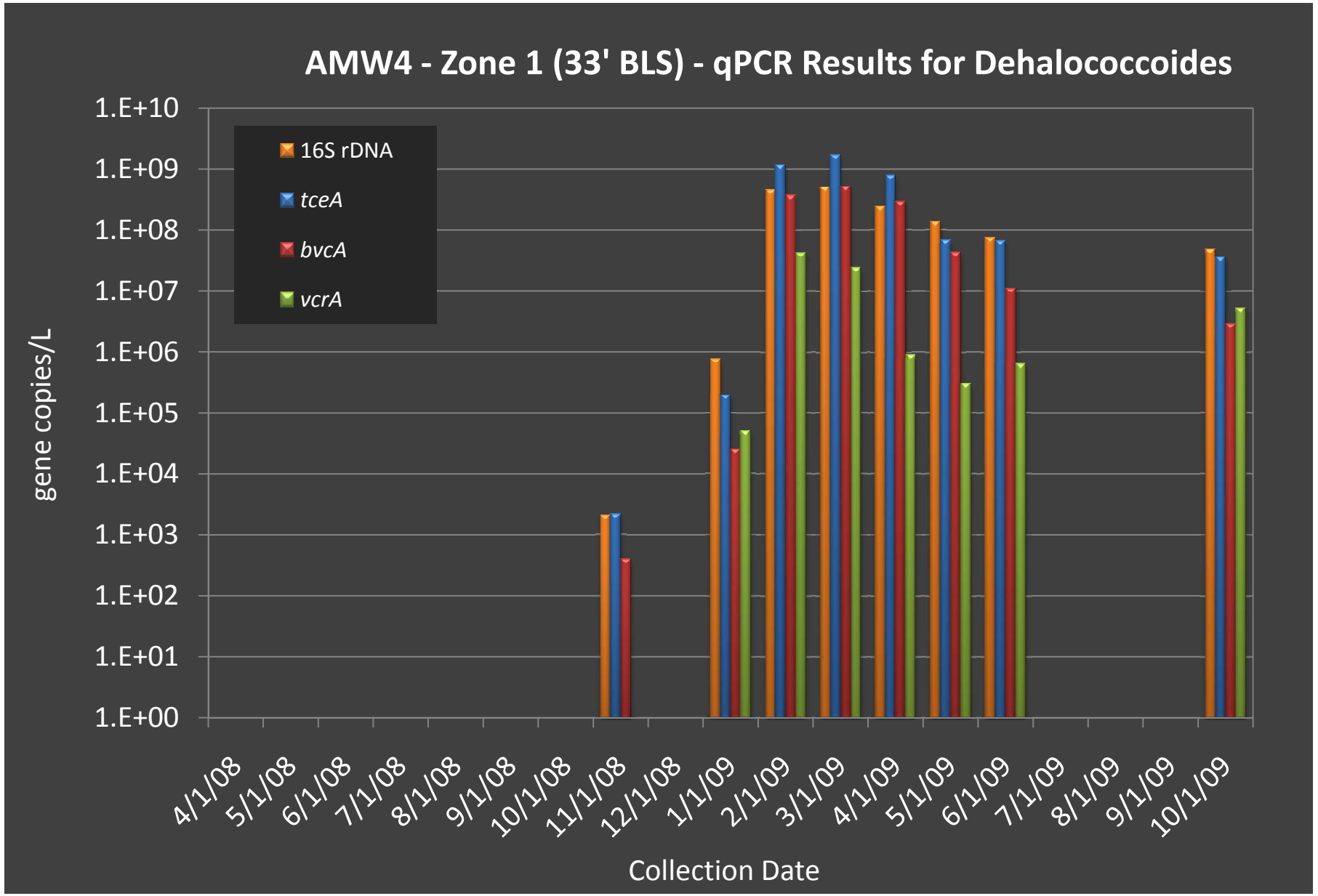
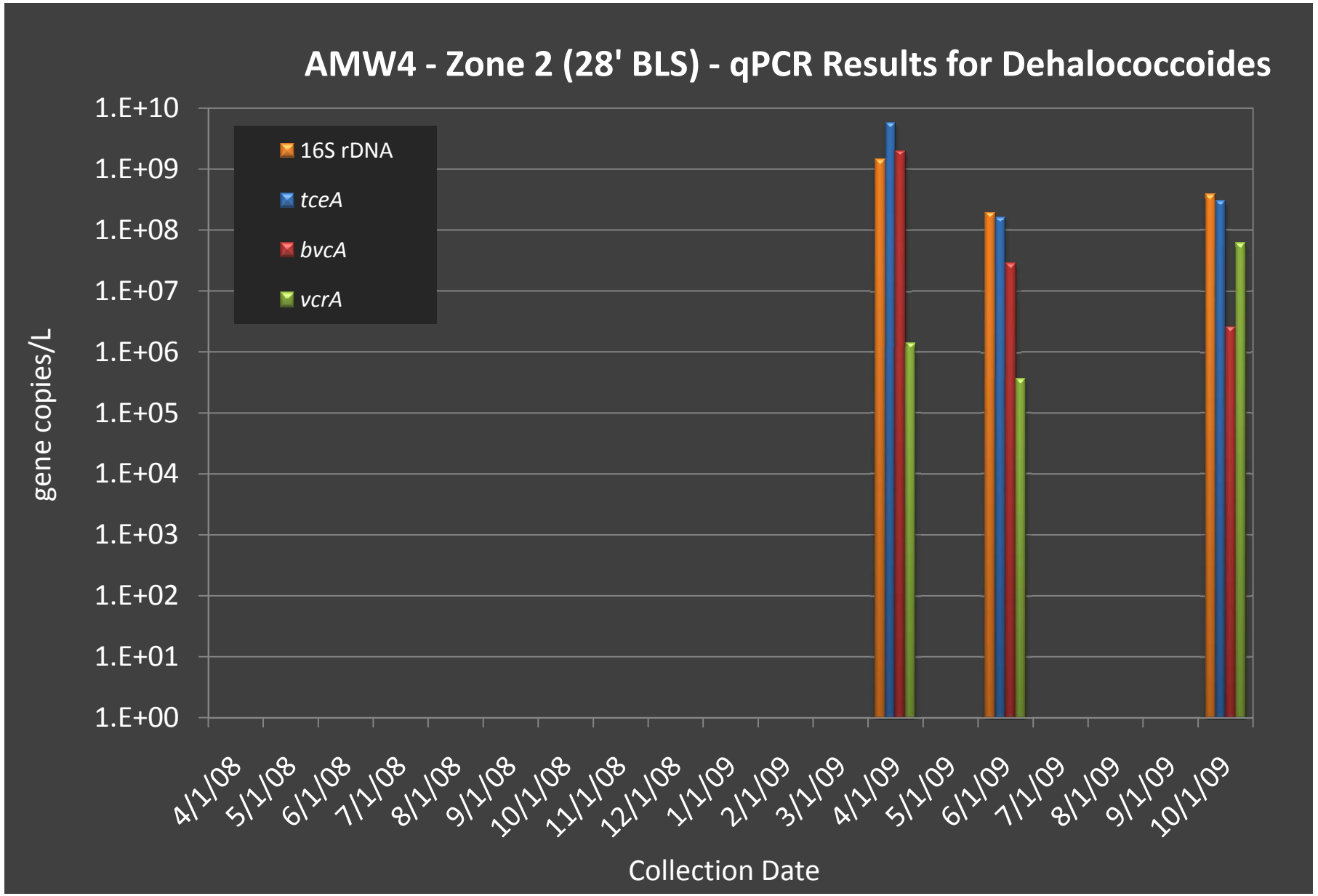
Seal Beach
Groundwater Bioaugmentation



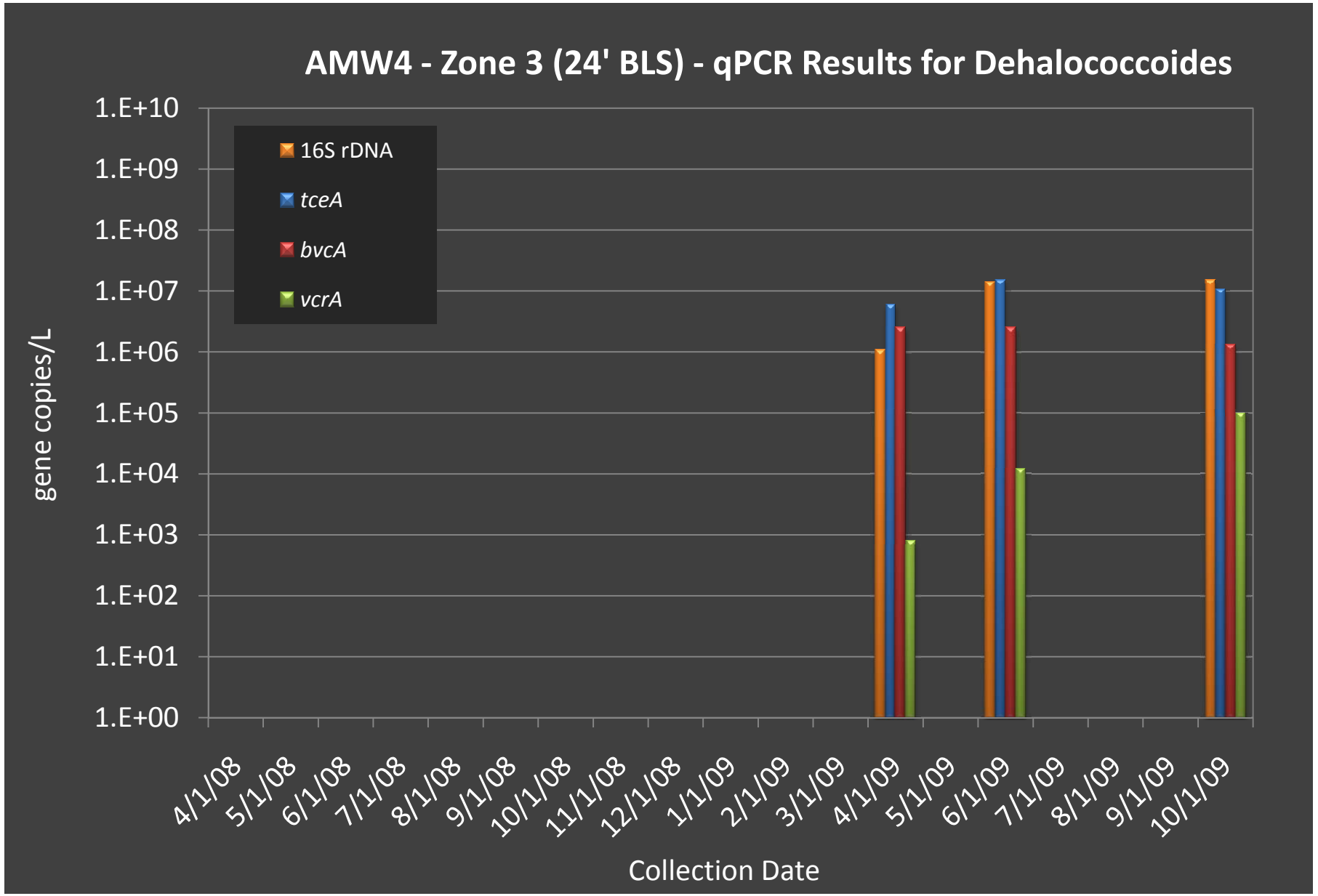
Recirculation system was shut off between 9/2/2008 and 1/6/2009.

Seal Beach
Groundwater Bioaugmentation



Recirculation system was shut off between 9/2/2008 and 1/6/2009.

Seal Beach
Groundwater Bioaugmentation



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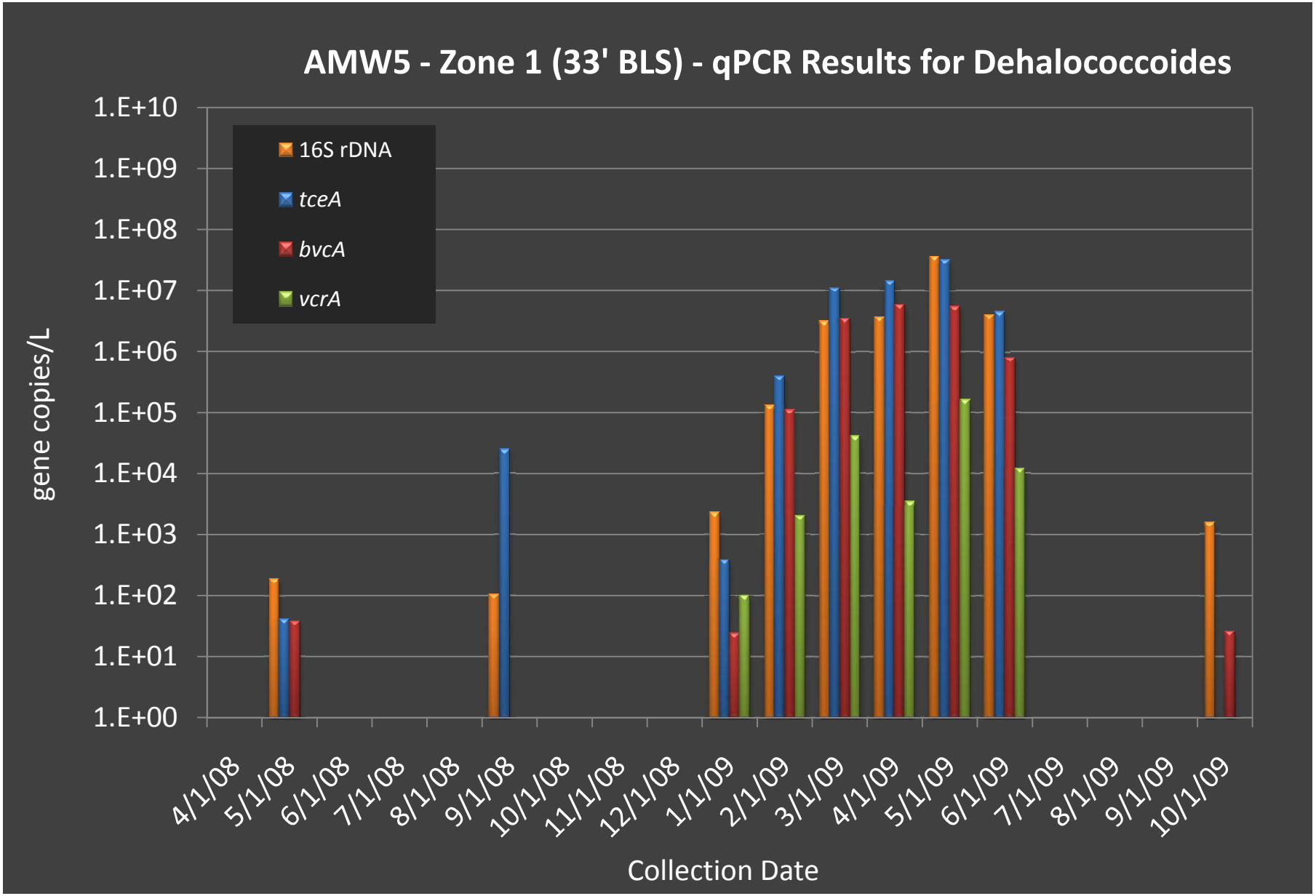
Seal Beach
Groundwater Bioaugmentation



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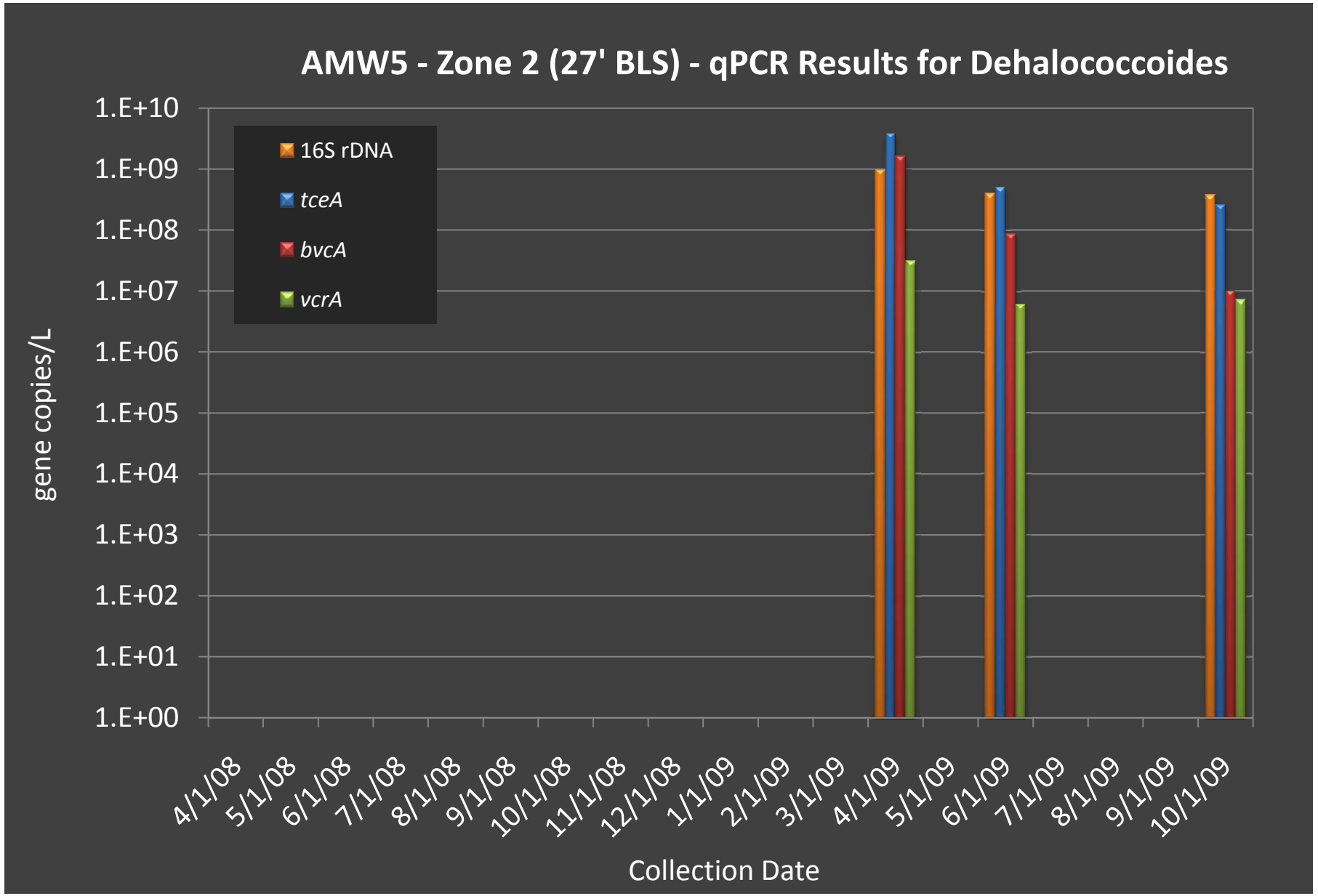
Seal Beach
Groundwater Bioaugmentation



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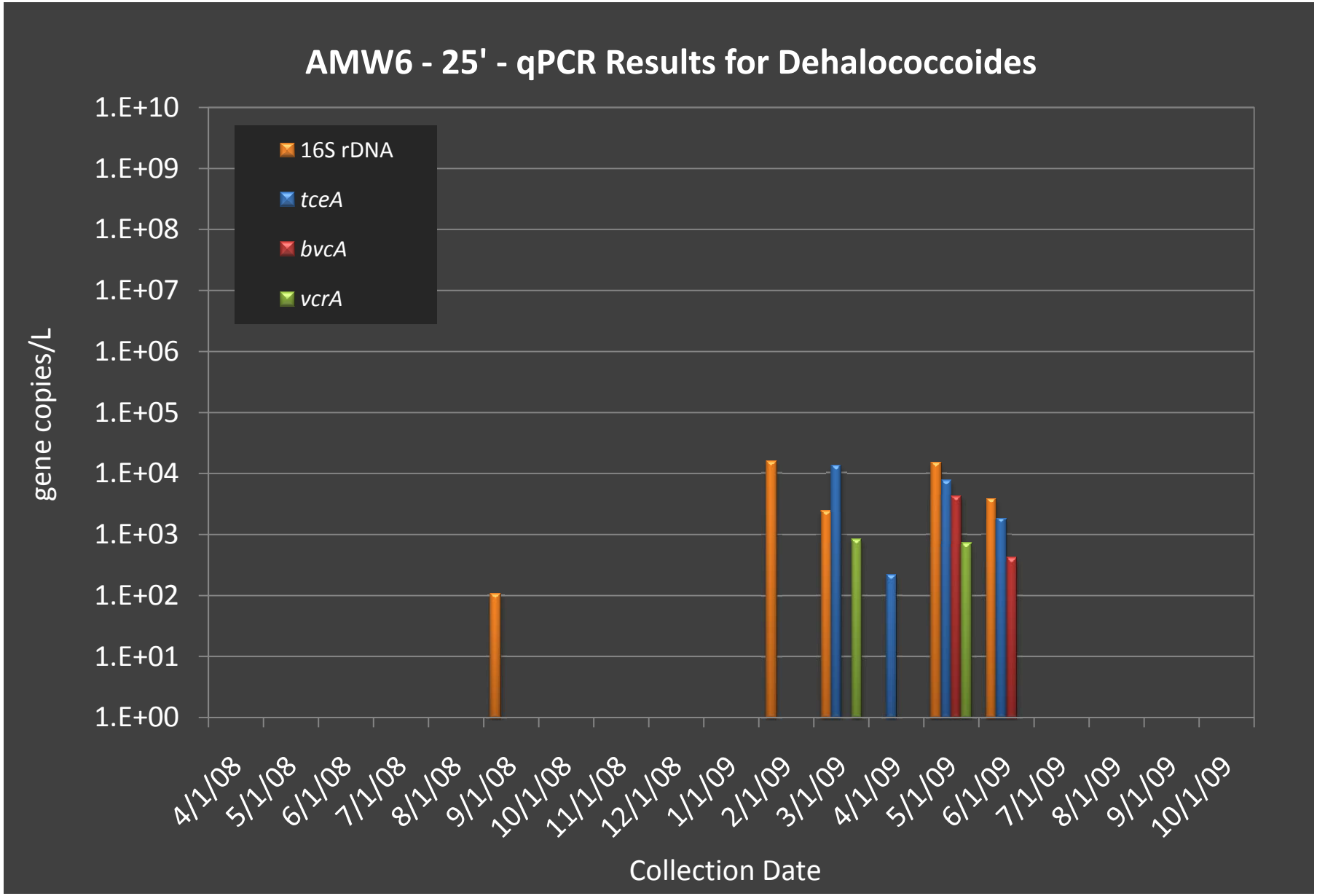
Seal Beach
Groundwater Bioaugmentation



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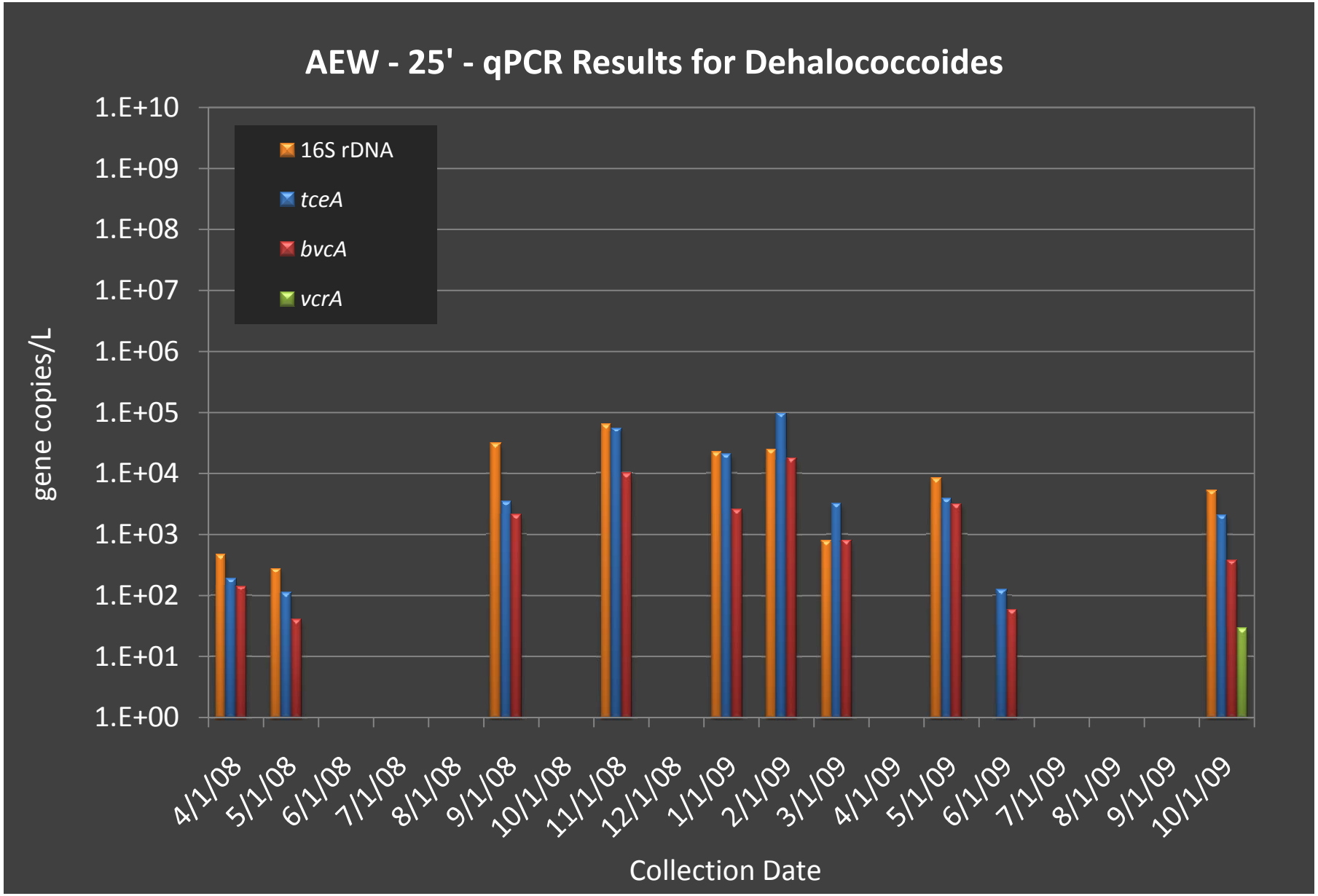
AMW6-25, DHC_Act_Seal Beach_Oct 2009.xls

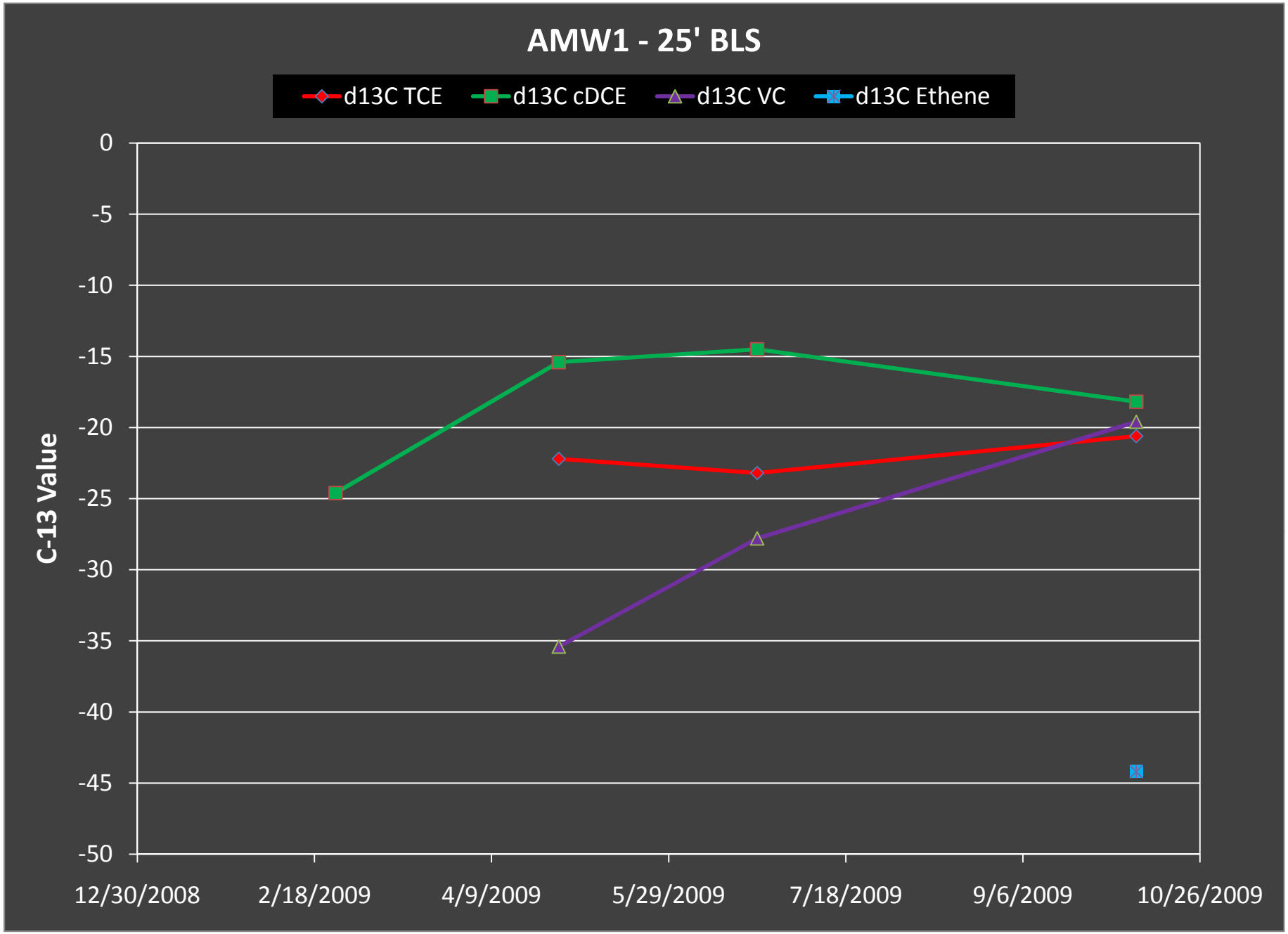
Seal Beach
Groundwater Bioaugmentation



Recirculation system was shut off between 9/2/2008 and 1/6/2009.

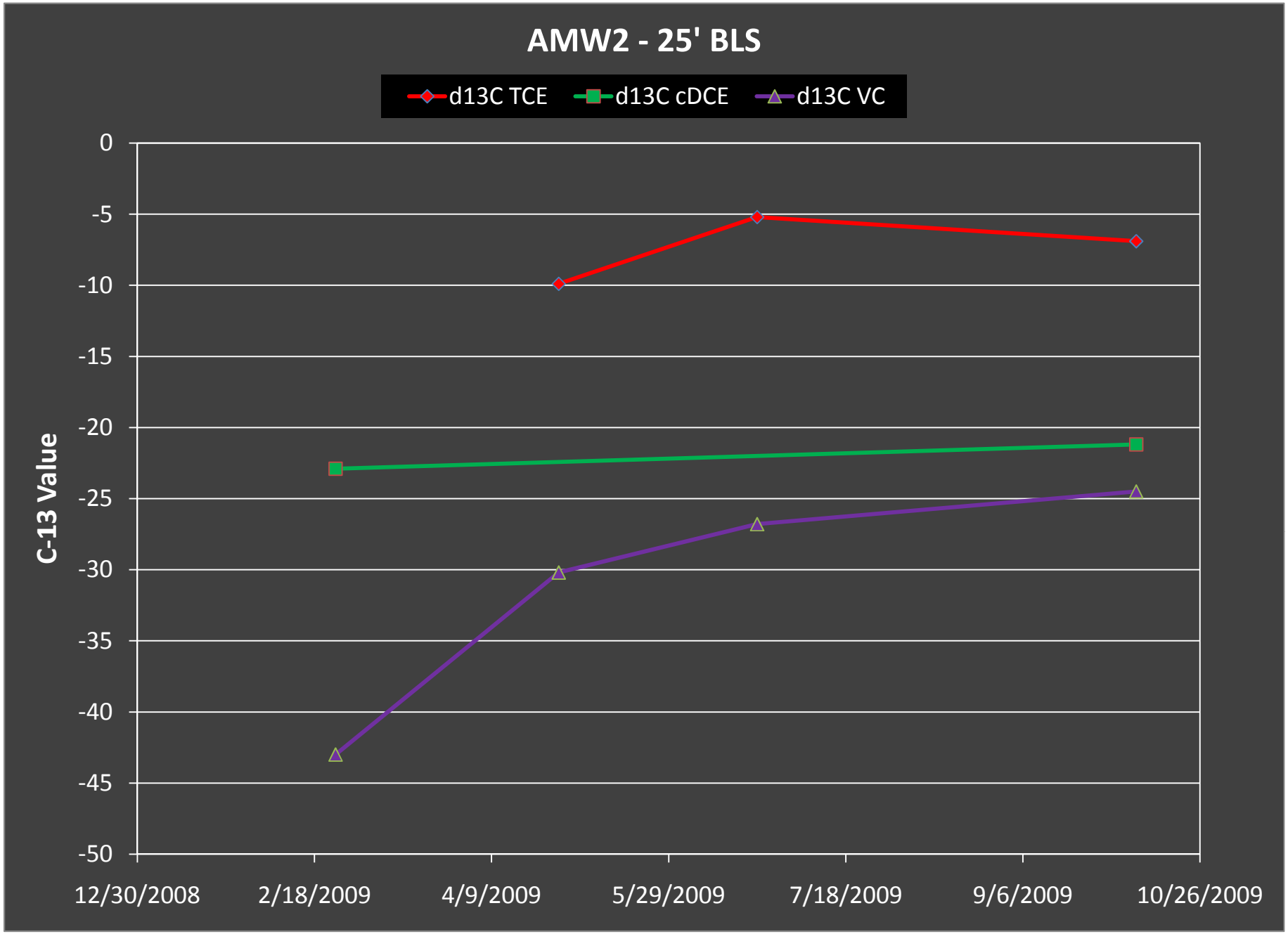
CSIA Results

Seal Beach
Groundwater Bioaugmentation



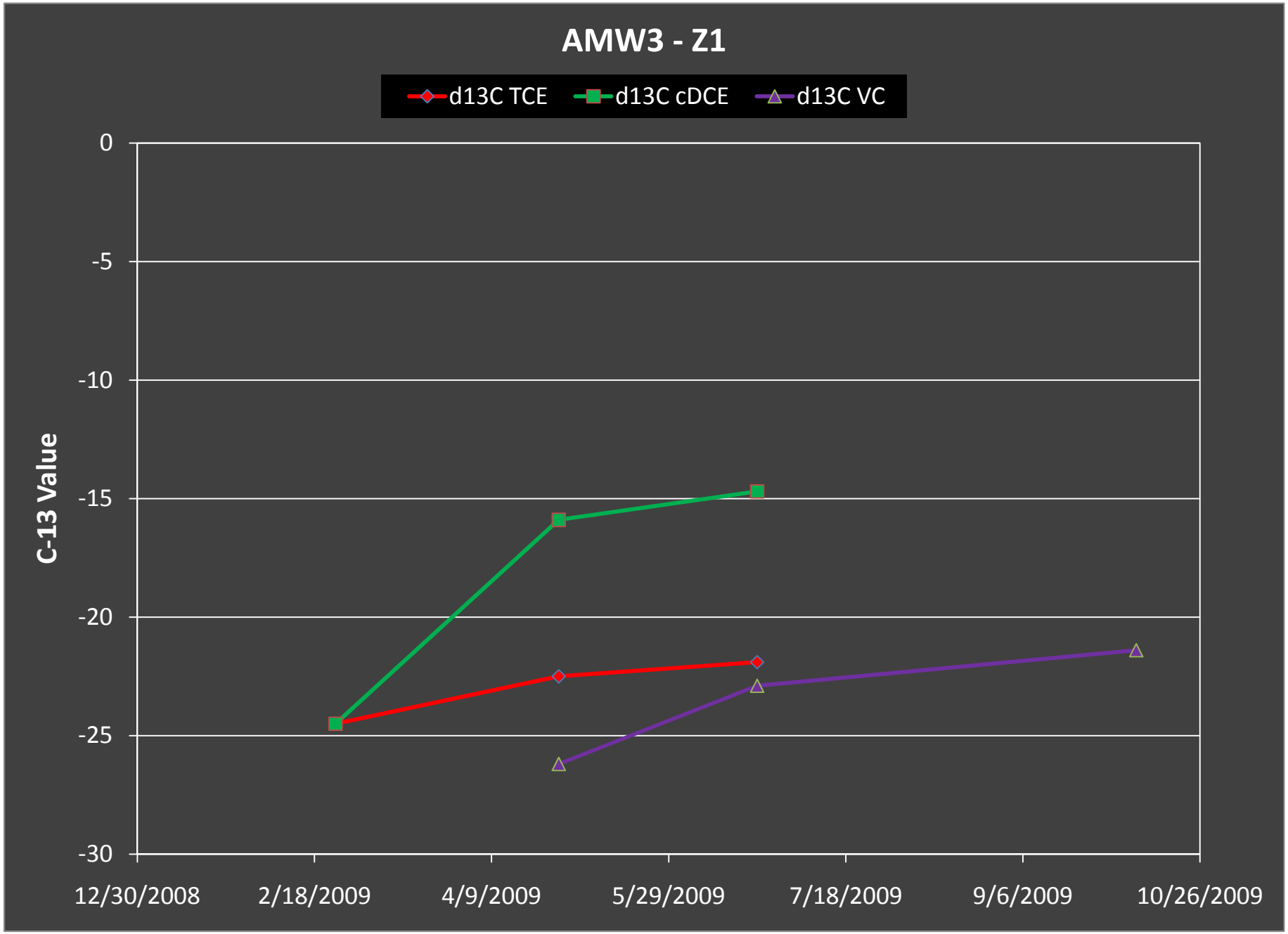
Recirculation system was shut off between 9/2/2008 and 1/6/2009.

Seal Beach
Groundwater Bioaugmentation



Recirculation system was shut off between 9/2/2008 and 1/6/2009.

Seal Beach
Groundwater Bioaugmentation

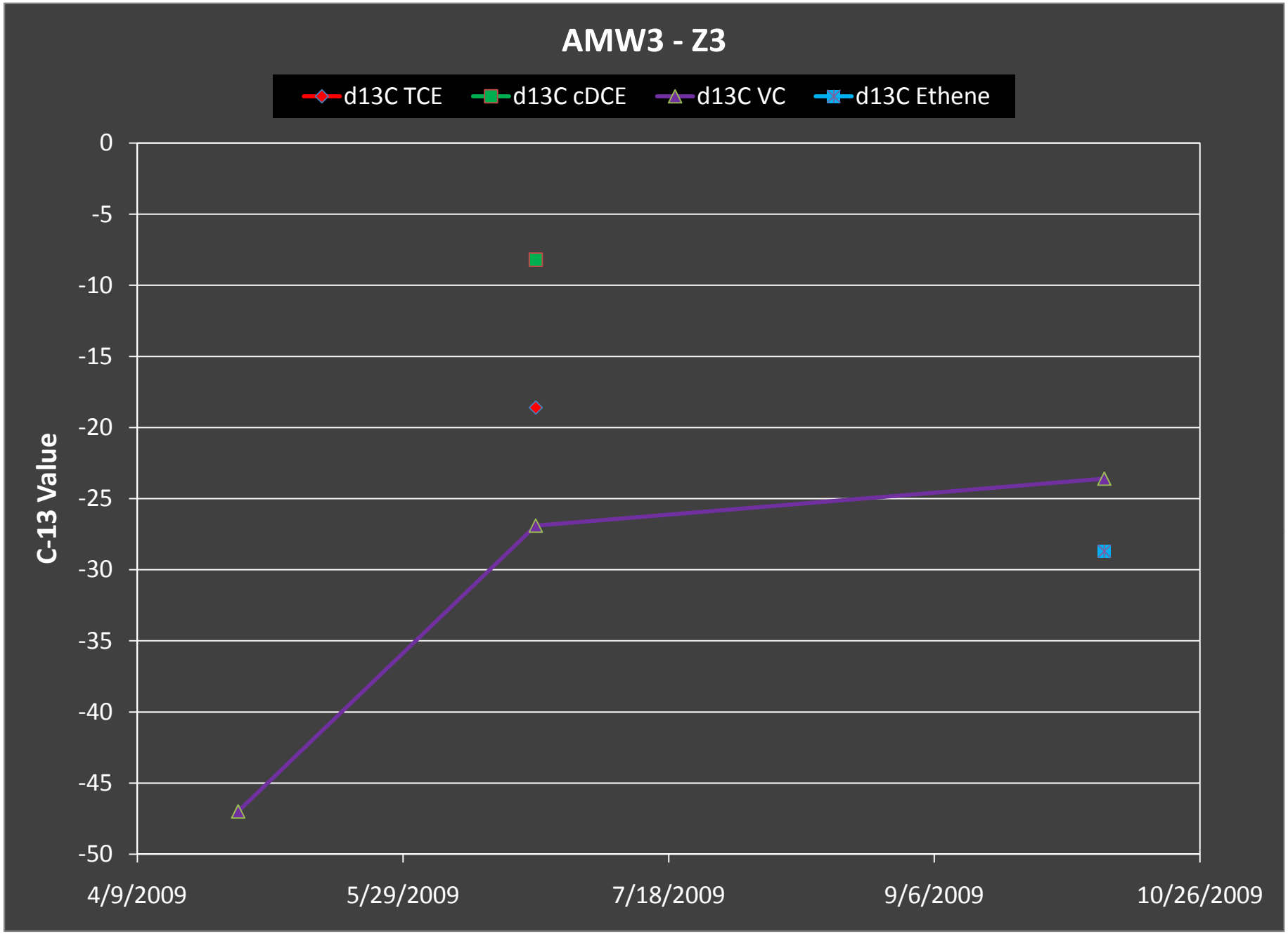


Recirculation system was shut off between 9/2/2008 and 1/6/2009.

Seal Beach
Groundwater Bioaugmentation

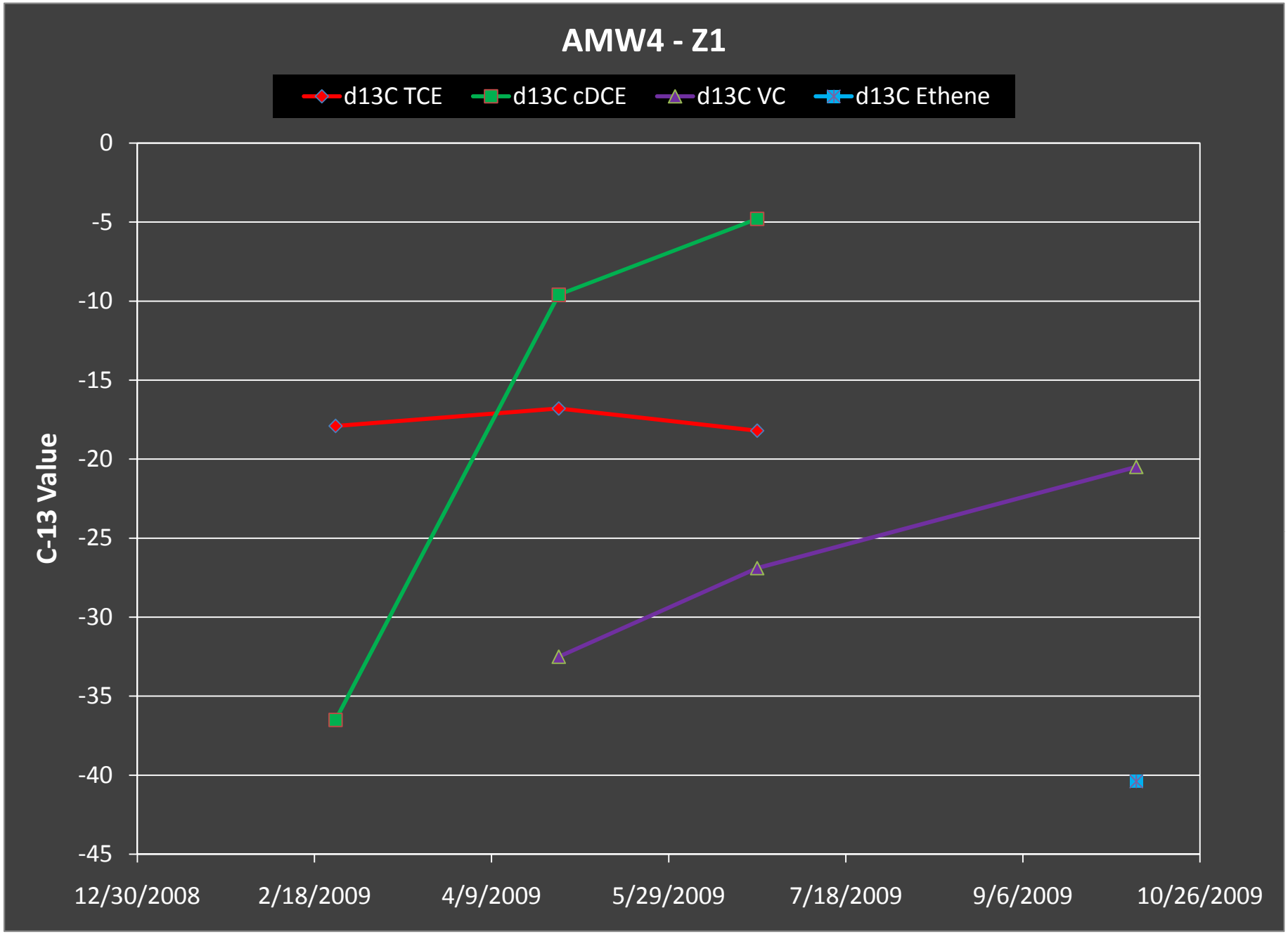
Recirculation system was shut off between 9/2/2008 and 1/6/2009.

Seal Beach
Groundwater Bioaugmentation



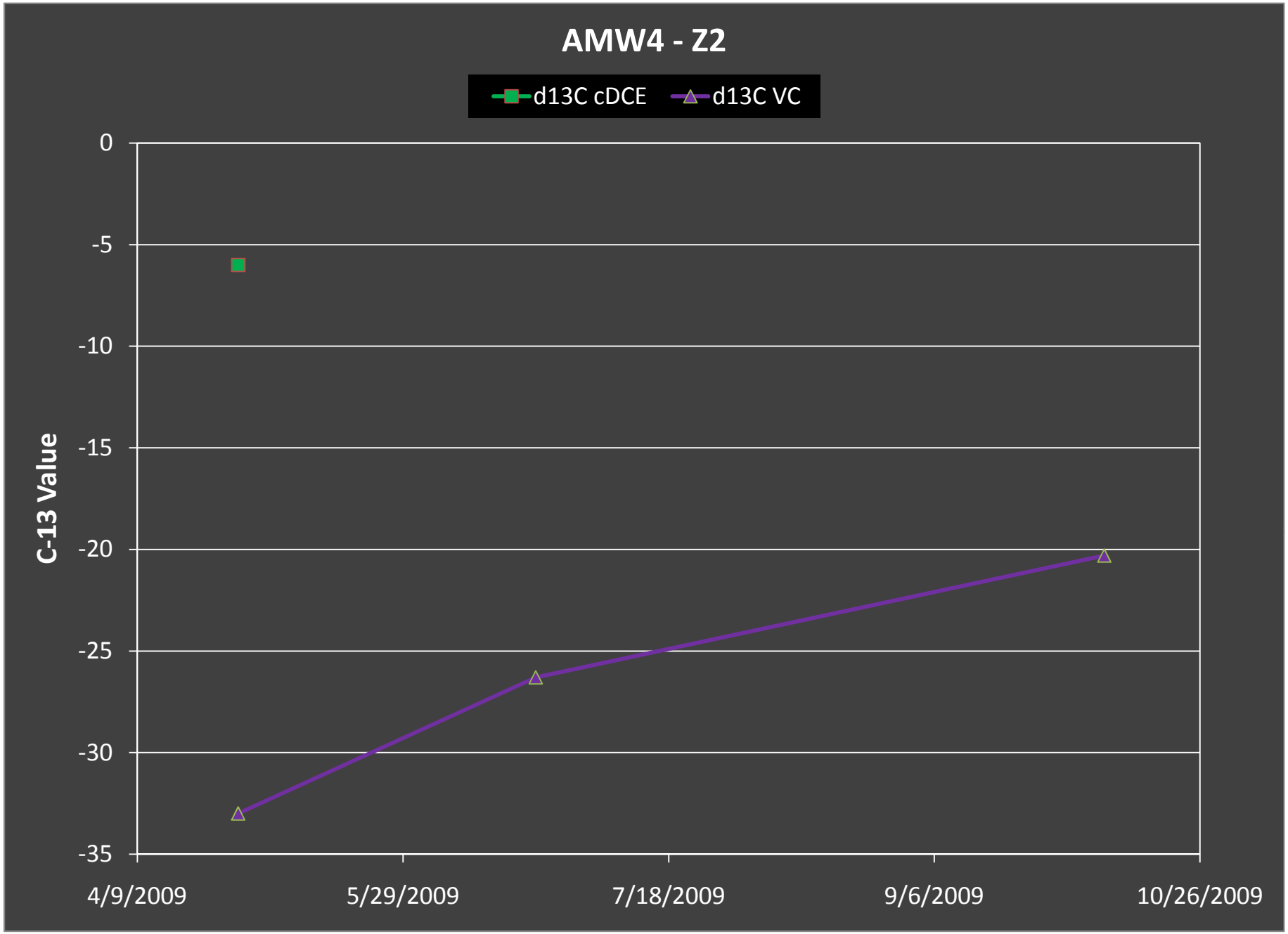
Recirculation system was shut off between 9/2/2008 and 1/6/2009.

Seal Beach
Groundwater Bioaugmentation



Recirculation system was shut off between 9/2/2008 and 1/6/2009.

Seal Beach
Groundwater Bioaugmentation

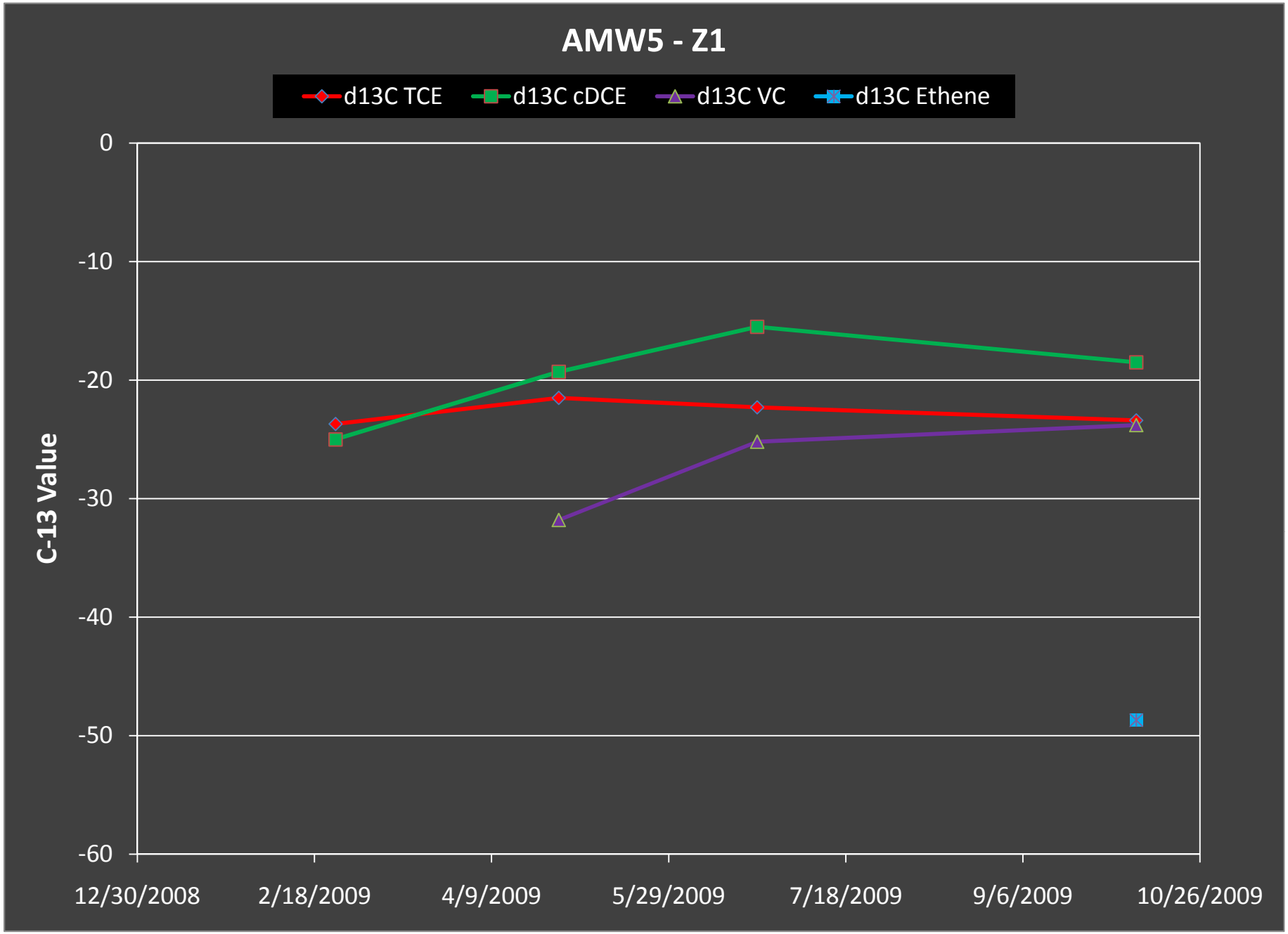


Recirculation system was shut off between 9/2/2008 and 1/6/2009.

Seal Beach
Groundwater Bioaugmentation

Recirculation system was shut off between 9/2/2008 and 1/6/2009.

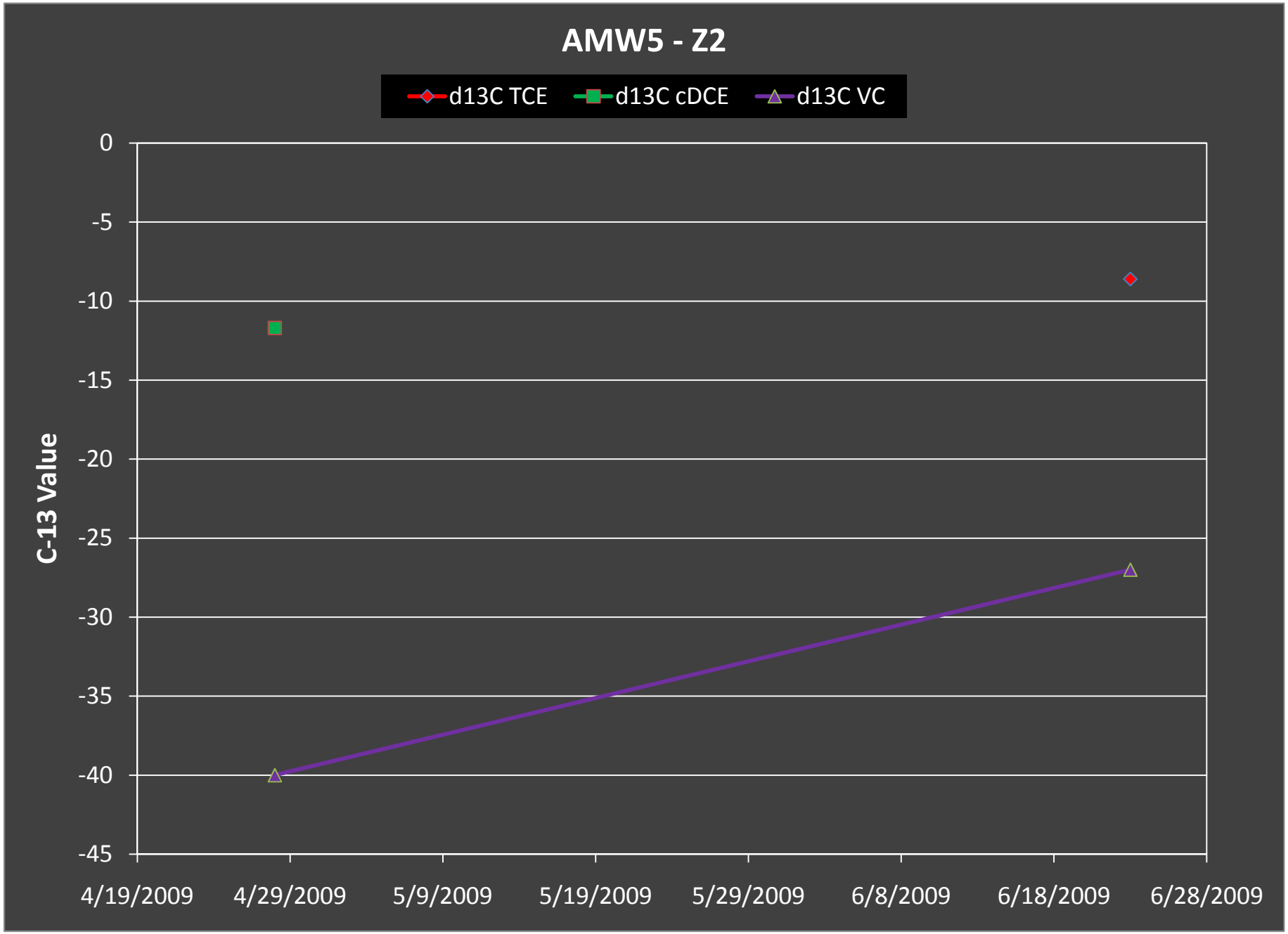
Seal Beach
Groundwater Bioaugmentation



Recirculation system was shut off between 9/2/2008 and 1/6/2009.

AMW5-Z1, CSIA_charts.xlsx

Seal Beach
Groundwater Bioaugmentation



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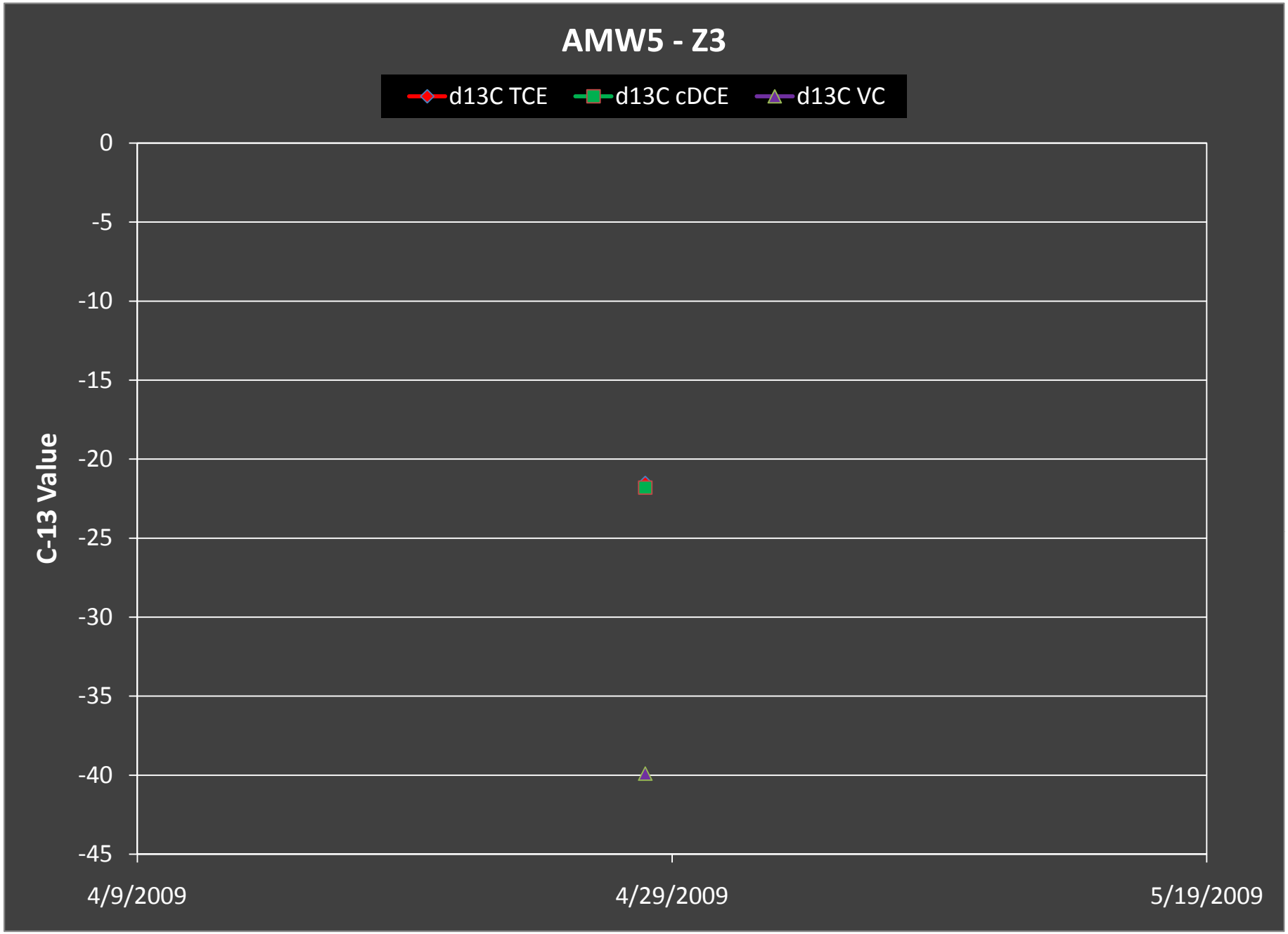
Seal Beach
Groundwater Bioaugmentation



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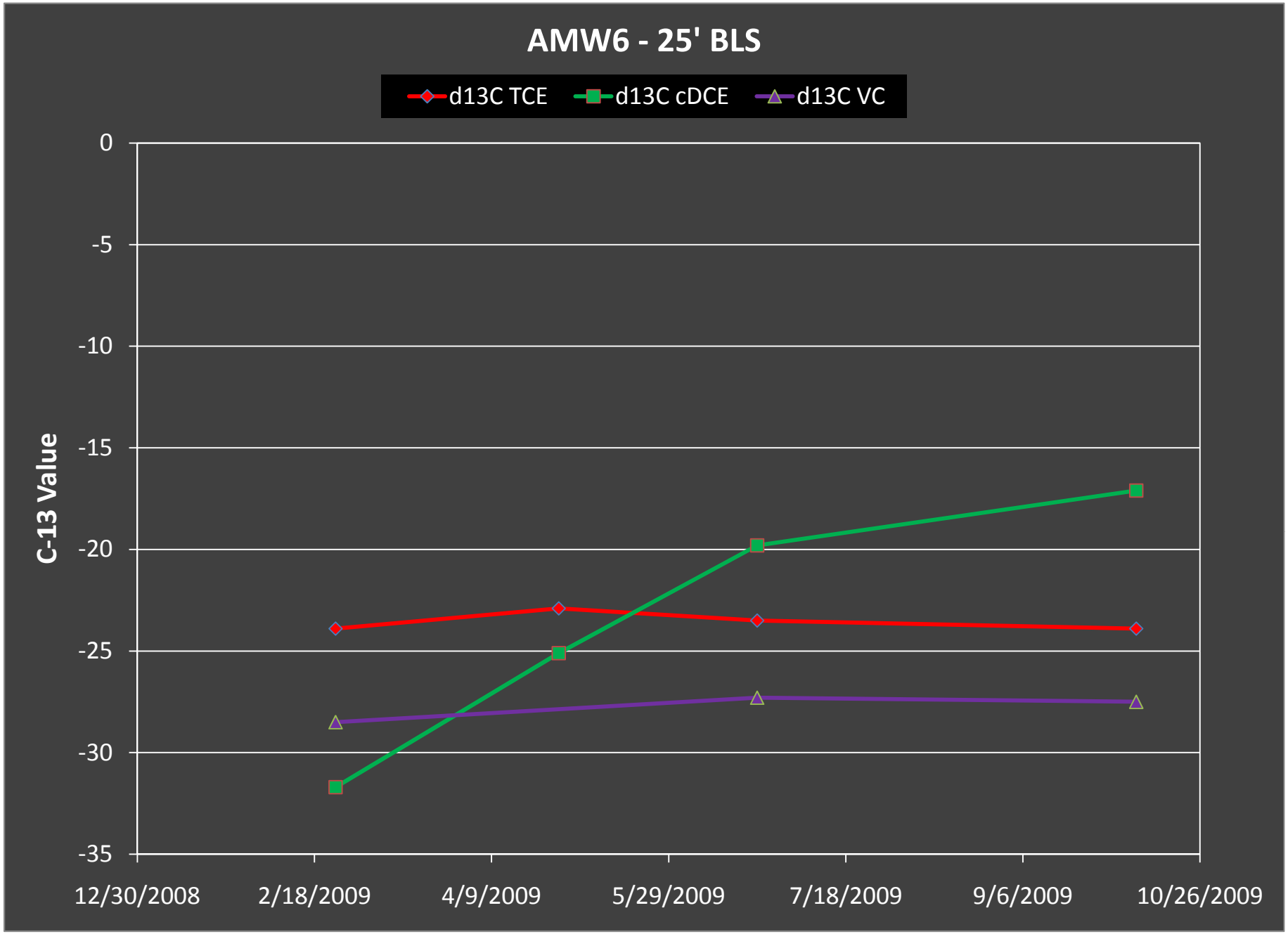
Seal Beach
Groundwater Bioaugmentation



Recirculation system was shut off between 9/2/2008 and 1/6/2009.

Appendix I
Passive Cell Concentration Trends

PASSIVE CELL Monitoring Data Summary NAVFAC Naval Weapons Station - Site 70		Tetrachloroethene	Trichloroethene	cis-1,2-Dichloroethene	trans-1,2-Dichloroethene	Vinyl Chloride	Ethene	Ethane	Methane	Alkalinity	Nitrate	Sulfate	Chloride	Chemical Oxygen Demand	Dehalococcoides - 16S rRNA	Dehalococcoides - tceA	Dehalococcoides - bvcA	Dehalococcoides - vcrA	pH	ORP (Mv)	DO (mg/L)	Conductivity (µmhos/cm)	Ferrous Iron
	Units:	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	mg/L	mg/L	mg/L	mg/L	mg/L	gene copies/L					mV	mg/L		mg/L
PIW-1	4/23/08	33	28	3.1	1.5 U	1.5 U	5 U	100	2300	1900	0.04 J	1600	350	18	ND	NS	NS	NS	7.39	190.9	0.65	6562	0
	9/5/08	49	85	5.9	0.7	0.2 J	5 U	57	1300	1600	0.25 U	2200	520	170	ND	ND	ND	ND	7.41	-26.8	0.68	6597	0
	10/16/08	51	71	4.6	0.4 J	0.5 U	5 U	47	1200	1600	0.25 U	2200	530	47	NS	NS	NS	NS	7.09	-59.8	1.18	7589	0.03
	11/3/08	38	54	3.6	1 U	1 U	5 U	5 U	94	1600	0.25 U	2200	530	99	ND	ND	ND	ND	7.37	-190.2	0.61	6903	0.02
	1/28/09	33	35	4.2	1 U	9.4	5 U	56	2600	1500	0.25 U	2700	590	28	1.15E+07	5.51E+06	ND	1.56E+06	7.27	-67.6	2.36	8929	0.12
	2/23/09	26	42	3.7	0.2 J	0.6 J	5 U	96	2800	1600	0.25 U	2700	600	28	2.75E+07	8.15E+07	ND	1.38E+07	7.29	-220.8	1.08	7590	0
	3/30/09- 25 ft	21	48	10	0.3 J	0.7	5 U	120	3500	1600	0.1 U	2500	530	28	7.83E+07	3.30E+08	ND	2.42E+07	7.2	-183.6	3.31	8287	0.49
	3/30/09- 35 ft	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	30	NS	NS	NS	NS	7.09	-272.1	2.01	8295	0.61
	4/27/09	11	26	23	0.3 J	4.3	10 U	140	4000 b	1700	0.1 U	2300	490	25	5.55E+07	2.63E+08	ND	1.05E+07	7.24	-280.4	16.29	7467	0.5
	5/28/09	7.7	17	16	0.3 J	11	10 U	94	5300	1700	0.25 U	2100	430	32	2.99E+06	1.69E+06	2.50E+03	3.00E+05	7.33	-229	1.24	6709	0.1
	6/23/09	5.7	13	8.8	0.3 J	19	2 J	59	7300	1600	0.25 U	1900	400	44	5.70E+06	1.00E+07	ND	1.20E+06	7.48	-310.3	0.24	6757	0
	10/15/09	4.1	8.5	2.7	0.4 J	12	4 J	6	9500	1600	0.25 U	2100	460	46	2.92E+05	1.48E+05	ND	2.10E+04	7.3	-288.3	0.59	6483	0
PIW-2	4/22/08	100 U	20000	73 J	100 U	100 U	5 U	8	230	600	0.13 J	3900	3600	71	ND	NS	NS	NS	6.68	403.6	1.17	15280	0
	9/2/08	22 J	6100	72	42 U	42 U	5 U	5 U	74	1400	0.25 U	3300	2300	1700	ND	ND	ND	ND	5.99	-256.8	2.02	1166	0
	10/15/08	6.3 J	4100	53	13 J	25 U	5 U	5 U	62	1900	0.25 U	3000	1900	1900	NS	NS	NS	NS	6.25	-168.3	0.78	12740	>3.3
	11/3/08	0.5 J	240	3.9	0.7 J	1.3 U	5 U	5 U	6	3100	0.1 U	600	210	4900	ND	ND	ND	ND	6.73	-236.1	0.43	6160	2.92
	1/27/09	1.3 U	2.3	0.7 J	0.4 J	19	17	5 U	690	5000	0.1 U	1700	510	8900	2.15E+08	3.74E+08	ND	5.49E+07	6.36	-208.9	0.57	12.69	>3.3
	2/23/09	0.4 J	12	2.5	1 U	23	5 U	5 U	1600	5300	0.1 U	990	490	8300	2.30E+09	6.98E+09	ND	1.69E+09	6.64	-345.9	0.57	10320	0
	3/30/09	0.5 J	41	5.5	1 U	10	5 U	5 U	1800	4400	0.5 U	1400	700	4100	6.81E+08	2.76E+09	ND	2.24E+08	6.7	-363.2	2.3	11540	0
	4/27/09	1 U	44	5.6	1 U	6	10 U	10 U	2900	4400	0.1 U	1100	570	3800	8.63E+08	3.64E+09	ND	1.14E+08	6.83	-372.1	20.71	9539	NM
	5/27/09	1.3 U	22	3.5	1.3 U	9.5	3 J	5 U	3200	5600	0.25 U	1000	490	7200	1.21E+09	1.05E+09	ND	1.70E+08	6.34	-356.2	46.31	10940	0
	6/22/09	0.5 U	17	2.9	0.2 J	7.7	2 J	5 U	1800	6000	0.25 U	1000	480	8600	2.65E+08	1.60E+09	ND	3.40E+07	6.69	-351.8	1	12000	0
	10/15/09	1 U	11	2.8	0.3 J	8.7	4 J	5 U	6300	2800	0.1 U	930	490	920	2.48E+07	1.63E+07	ND	1.90E+06	5.45	-344.7	0.83	6449	0
PIW-3	4/23/08	17 U	11000	82	7.5 J	17 U	5 U	10	150	620	0.5 U	3100	1800	30	ND	NS	NS	NS	6.57	101.6	0.57	10219	0
	9/5/08	83 U	11000	92	83 U	83 U	5 U	8	170	800	0.25 U	2700	1500	390	ND	ND	ND	ND	5.82	-139.2	1.05	7748	3.03
	10/15/08	31 U	12000	85	8.8 J	31 U	5 U	7	140	1200	0.25 U	2100	1500	740	NS	NS	NS	NS	6.44	-290.1	0.7	8362	>3.3
	11/3/08	2 U	270	260	2 U	2 U	5 U	5 U	14	3300	0.1 U	15	89	5700	ND	ND	ND	ND	6.64	-249.3	0.68	6052	>3.3
	1/27/09	0.5 U	1.4	1.1	0.3 J	30	24	5 U	2500	4800	0.1 U	8.9	65	8900	1.91E+09	9.89E+08	ND	4.37E+08	6.33	-209.2	0.5	9334	3.13
	1/27/2009-K	1.3 U	1.4	0.5 J	1.3 U	25	26	5 U	2300	4800	0.1 U	11	67	10000	3.12E+09	1.80E+09	ND	8.19E+08					
	2/23/09	1.3 U	2.1	1.4	1.3 U	4.7	5	5 U	3100	5300	0.1 U	1 U	14	12000	1.52E+09	5.27E+09	ND	1.17E+09	6.35	-211.7	2.43	8363	3.05
	3/30/09	1.3 U	6.5	2.4	1.3 U	4.2	5 U	5 U	3900	2800	0.1 U	0.77 J	190	4800	3.45E+08	1.17E+09	ND	8.20E+07	6.25	-292.4	2.01	4889	>3.3
	4/27/09	1.3 U	1.2 J	1.3	1.3 U	6.1	25 U	25 U	4600	3600	0.1 U	0.14 J	68	5900	1.11E+09	5.09E+09	ND	1.52E+08	6.32	-280.3	4.72	7098	3.3
	4/27/09-K	1.3 U	1.0 J	1.3	1.3 U	5	25 U	25 U	4200	3500	0.1 U	0.12 J	70	5900	1.36E+09	6.06E+09	ND	1.71E+08					
	5/27/09	0.5 U	3.4	7.1	0.3 J	11	35	4 J	2900	4300	0.05 U	2.2	98	7300	2.89E+08	1.69E+08	ND	3.90E+07	6.2	-251.6	11.66	6934	3.15
	6/22/09	0.5 U	5.4	2.2	0.2 J	3.8	6	5 U	2700	7000	0.1 U	8.1	100	14000	5.29E+07	7.40E+07	ND	8.60E+06	6.53	-202.3	0.73	11030	2.98
	10/13/09	0.5 U	0.7	2.7	0.4 J	4.2	19	3 J	10000	2700	0.05 U	0.61	130	2100	1.48E+07	5.45E+07	ND	1.90E+06	6.82	-94.3	0.65	4477	>3.3
	10/13/2009-K	0.5 U	1	3.4	0.5 J	5.2	18	2 J	10000	2700	0.05 U	2.3	130	2100	1.81E+07	1.16E+07	ND	2.50E+06					
PMW-1	4/23/08	18	1100	48	6.5 J	10 U	5 U	5 U	35	1400	0.53	3800	1000	24	ND	NS	NS	NS	6.9	161.1	0.45	10673	0
	4/23/2008 - K	19	1200	49	6.4 J	8.3 U	5 U	5 U	37	1400	0.51	3800	1000	28	NS	NS	NS	NS					0
	9/5/08	15	2000	66	8.8 J	10 U	5 U	5 U	29	890	0.7	4300	1400	32	ND	1.03E+01	ND	ND	6.45	146.2	0.6	9118	0
	10/16/08	13	1800	55	9.8	3.1 U	5 U	5 U	27	880	0.52	4300	1300	23	NS	NS	NS	NS	6.45	102.7	1.2	10630	0
	11/4/08	11 J	1600	64	10 J	17 U	5 U	5 U	14	880	0.72	4700	1400	25	ND	ND	ND	ND	6.69	159.8	0.83	9533	0
	1/28/09	9.9 J	1500	54	9.3 J	10 U	5 U	5 U	31	850	0.67	4800	1300	28	3.48E+02	4.88E+01	ND	7.16E+01	6.66	-19.7	2.41	11560	0
	2/23/09	11	1700	79	14	10 U	5 U	12	320	870	0.76	5100	1400	25	ND	ND	3.77E+02	ND	6.64	-266	1.05	10439	NM
	3/30/09	10 J	1400	64	12 J	13 U	5 U	6	150	880	0.66	4600	1300	23	1.58E+03	6.28E+03	ND	4.18E+02	6.55	-85.9	2.77	10900	0
	4/28/09	13	1400	65	9.4 J	10 U	5 U	7	140	850	0.4 J	4400	1200	30	1.33E+02	7.17E+02	ND	4.90E+01	6.57	91.6	0.58	10280	NM
	5/28/09	12	1500	76	9.6 J	10 U	5 U	8	160	870	0.4 J	4300	1100	17	6.46E+01	2.67E+02	ND	1.40E+02	6.44	-4.7	0.72	9504	0.02
	6/23/09	7.1 J	1400	69	8.9 J	13 U	5 U	5 J	85	830	1 U	4300	1100	57	8.83E+02*	8.50E+02	ND	1.5E+02*	6.9	-185.4	0.39	9596	0
	10/15/09	6.2 J	1600	67	12	10 U	5 U	2 J	22	910	0.85	4900	1300	61	1.41E+02*	ND	1.3E+01*	2.8E+01*	6.68	-36.2	0.83	10190	0
PMW-2	4/22/08	11 J	2600	61	18 J	25 U	5 U	5 U	15	1100	0.11 J	3400	1400	28	ND	NS	NS	NS	6.94	483.9	1.01	10928	0
	9/5/08	20	3400	74	16 J	20 U	5 U	5 U	39	900	0.5 U	5400	2200	42	ND	ND	ND	ND	6.66	85.2	0.3	1194	0
	10/16/08	15	2900	64	13	5 U	5 U	5 U	60	1100	0.25 U	4400	1800	53	NS	NS	NS	NS	6.77	-63.1	1.65	10610	1.01
	11/4/08	15 J	2600	64	10 J	25 U	5 U	5 U	7	1000	0.5 U	5000	2200	120	ND	ND	ND	ND	7.07	-74.4	2.67	10870	2.19
	11/4/2008 - K	19	3000	65	15	10 U	5 U	5 U	71	970	0.5 U	5100	2300	110	ND	ND	ND	ND					
	1/28/09	13 J	2300	41	7.9 J	17 U	5 U	5 U	59	1200	0.25 U	2700	1200	36	ND	ND	ND	ND	7.6	-49.9	1.73	4312	0.53
	2/23/09	16 J	1800	43	7.3 J	17 U	5 U	5 U	70	200	0.05 U	550	240	53	ND	ND	ND	ND	7.49	-155.9	0.87	5265	2.72
	3/30/09	1.9	88	7.8	0.4 J	0.5 U	5 U	5 U	5 U	1500	0.05 J	390	51	13	2.23E+03	1.07E+04	ND	7.23E+02	8	-110.6	6.14	3495	0.01
	4/28/09	3.8	280	6.5	0.5 J	1 U	5 U	5 U	5 J	1500	0.1 U	440	87	19	1.06E+02	1.12E+03	ND	4.21E+01	8.25	36.9	1.46	3339	0
	4/28/09-K	3.3	370	9.1	0.9 J	2.5 U	5 U	5 U	12	1699	0.1 U	1000	460	84	ND	ND	ND	ND					
	5/28/09	13	1600	8.5	2.9	2.5 U	5 U	5 U	480	1600	0.1 U	420	63	11	4.16E+03	2.10E+03	1.40E+03	6.10E+01	7.23	-93.8	0.83	3353	0
	6/23/09	30 J	4400	14 J	42 U	42 U	5 U	5 J	3900	1800	0.05 U	400	72	25	ND	2.9E+02*	ND	6.9E+01*	6.79	53	0.46	3594	0.97
	10/15/09	18 J	2200	15 J	25 U	25 U	1 J	2 J	3200	2000	0.1 U	690	190	410	ND	ND	ND	ND	6.7	-121.6	0.33	3310	1.13
	4/23/08	100 U	49000	68 J	100 U	100 U	5 U	7	220	360	0.03 J	2000	2500	64	1.10E+03	8.60E+03	ND	ND	6.61	354.8	1.05	10070	0

PASSIVE CELL Monitoring Data Summary NAVFAC Naval Weapons Station - Site 70		Tetrachloroethene	Trichloroethene	cis-1,2-Dichloroethene	trans-1,2-Dichloroethene	Vinyl Chloride	Ethene	Ethane	Methane	Alkalinity	Nitrate	Sulfate	Chloride	Chemical Oxygen Demand	Dehalococcoides - 16S rRNA	Dehalococcoides - tceA	Dehalococcoides - bvcA	Dehalococcoides - vcrA	pH	ORP (Mv)	DO (mg/L)	Conductivity (µmhos/cm)	Ferrous Iron
	Units:	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	mg/L	mg/L	mg/L	mg/L	mg/L	gene copies/L					mV	mg/L		mg/L
PMW-3 Zone 1	9/2/08	360 U	61000	110 J	360 U	360 U	5 U	5	170	360	0.25 U	2000	2600	53	ND	ND	ND	ND	6.31	191.4	6.3	9122	0
	10/16/08	170 U	56000	90 J	170 U	170 U	5 U	7	200	370	0.25 U	1900	2500	95	NS	NS	NS	NS	6.35	15.1	2.17	9690	1.25
	11/3/08	310 U	61000	310 U	310 U	310 U	5 U	7	220	430	0.25 U	2100	2600	170	ND	ND	ND	ND	6.51	-88.6	0.72	9050	1.92
	1/27/09	360 U	46000	160 J	360 U	360 U	5 U	9	240	600	0.1 U	1900	1800	230	1.49E+07	6.28E+06	ND	4.52E+06	6.53	-200	1.13	9777	2.56
	2/23/09	360 U	41000	170 J	360 U	360 U	5 U	12	330	680	0.25 U	1900	2300	290	3.03E+08	9.76E+08	ND	2.18E+08	6.47	-153	1.8	8384	>3.3
	3/30/09	20 J	44000	150	8.7 J	25 U	5 U	6	160	590	0.25 U	1900	2400	170	5.84E+07	2.36E+08	ND	2.20E+07	6.26	-183.6	7.49	9589	2.67
	4/28/09	360 U	45000	260 J	360 U	360 U	1 J	7	180	500	0.1 U	2000	2600	150	8.04E+06	4.17E+07	ND	1.55E+06	6.38	-97.8	1.14	9089	3.3
	5/27/09	310 U	50000	230 J	310 U	310 U	1 J	7	200	450	0.25 U	2000	2700	74	1.47E+07	9.38E+06	ND	2.80E+06	6.24	-112	4.8	9282	3.26
	6/22/09	310 U	47000	190 J	310 U	310 U	5 U	6	190	410	0.25 U	2000	2600	290	3.71E+06	5.20E+06	ND	8.20E+05	6.71	-196.7	0.79	9432	2.86
	10/15/09	310 U	50000	110 J	310 U	310 U	2 J	6	240	360	0.5 U	2000	2700	76	1.71E+06	4.22E+05	ND	1.80E+05	6.47	-21.6	0.84	8876	>3.3
PMW-3 Zone 2	4/23/08	19 J	4700	90	20 J	42 U	5 U	5 U	81	730	0.04 J	4200	2500	67	ND	NS	NS	NS	6.63	208.7	0.79	13923	0
	11/3/08	7.5	3100	69	16	7.1 U	5 U	5 U	86	650	0.1 U	3800	1700	30	ND	ND	ND	ND	6.68	-23.9	1.5	9867	0.18
	4/28/09	10	1300	17	4.7 J	10 U	5 U	2 J	70	4000	0.1 U	1800	660	3100	2.23E+05	1.58E+06	ND	6.50E+04	6.27	-205.4	11.92	9727	3.3
	6/22/09	9.3 J	1400	11	2.7 J	3.1 J	5 U	3 J	230	4100	0.25 U	1000	680	4000	3.78E+05	8.90E+05	ND	1.80E+05	6.56	-296.5	0.63	8791	>3.3
	10/15/09	15 J	3600	53	11 J	25 U	0.3 J	5 J	550	2100	0.5 U	2600	2000	1300	6.53E+04	1.44E+05	ND	8.4E+03*	6.25	-78	0.78	10460	>3.3
PMW-3 Zone 3	4/24/08	20	5400	74	24	3.1 U	5 U	5 U	160	750	0.5 U	3900	3400	100	ND	NS	NS	NS	6.68	117.8	0.9	13706	0
	11/3/08	16	4800	51	12 J	13 U	5 U	5 U	98	880	0.5 U	4400	3100	68	ND	ND	ND	ND	6.76	-3.2	1.81	13140	1.18
	4/28/09	43	4400	32 J	42 U	42 U	5 U	4 J	150	1700	0.1 U	5900	2600	890	ND	ND	ND	ND	6.46	-216.4	5.98	15.53	2.5
	6/22/09	29	2900	18 J	20 U	20 U	5 U	1 J	76	3000	1 U	5800	1600	3000	ND	ND	ND	ND	6.75	-294.1	0.51	15410	2.76
	10/15/09	20 J	2300	42 U	42 U	42 U	5 U	0.9 J	71	3100	1 U	5800	1100	2300	2.92E+02*	1.54E+02*	2.6E+01*	7.0E+01*	6.57	-103.2	1.09	13680	>3.3
PMW-3 Zone 4	4/24/08	17 U	1600	10 J	17 U	17 U	5 U	5 U	88	NS	NS	NS	NS	NS	NS	NS	NS	NS	7.47	-38.7	3.68	14267	0
MW-4 Zone 1	4/24/08	630 U	63000	630 U	630 U	630 U	5 U	7	180	350	0.09 J	2000	2500	58	ND	NS	NS	NS	6.82	14.7	0.39	9571	0
	4/24/2008 - K	500 U	61000	500 U	500 U	500 U	5 U	7	180	300	0.08 J	2000	2500	58	NS	NS	NS	NS					
	9/2/08	420 U	63000	160 J	420 U	420 U	5 U	9	240	380	0.25 U	2000	2200	44	ND	ND	ND	ND	6.5	166.8	4.07	8224	0
	10/16/08	71 U	56000	76	71 U	71 U	5 U	11	280	400	0.25 U	2000	2100	70	NS	NS	NS	NS	6.38	54	2.17	8577	0.09
	11/4/08	360 U	50000	310 J	360 U	360 U	5 U	11	290	410	0.25 U	2000	2100	74	ND	ND	ND	ND	6.6	52.3	1.03	7992	0.62
	1/27/09	360 U	51000	360 U	360 U	360 U	5 U	9	230	460	0.1 U	2000	2000	99	6.95E+07	4.09E+07	ND	2.73E+07	6.52	-35.4	1.54	8982	2.8
	2/23/09	360 U	41000	170 J	360 U	360 U	5 U	13	310	530	0.25 U	2000	2000	140	1.67E+08	5.29E+08	ND	1.47E+08	6.54	-215.9	1.39	7726	2.31
	3/30/09	360 U	45000	140 J	360 U	360 U	5 U	8	180	540	0.25 U	1900	1900	140	9.13E+07	2.83E+08	ND	2.62E+07	6.27	-173.4	8.99	8547	2.4

PASSIVE CELL Monitoring Data Summary NAVFAC Naval Weapons Station - Site 70		Tetrachloroethene	Trichloroethene	cis-1,2-Dichloroethene	trans-1,2-Dichloroethene	Vinyl Chloride	Ethene	Ethane	Methane	Alkalinity	Nitrate	Sulfate	Chloride	Chemical Oxygen Demand	Dehalococcoides - 16S rRNA	Dehalococcoides - tceA	Dehalococcoides - bvcA	Dehalococcoides - vcrA	pH	ORP (Mv)	DO (mg/L)	Conductivity (µmhos/cm)	Ferrous Iron
	Units:	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	mg/L	mg/L	mg/L	mg/L	mg/L	gene copies/L					mV	mg/L		mg/L
PI	4/28/09	360 U	42000	170 J	360 U	360 U	2 J	12	280	590	0.1 U	1900	1900	170	2.74E+07	1.33E+08	ND	5.19E+06	6.33	-154	1.73	8432	3.18
	5/27/09	250 U	41000	2100	250 U	250 U	3 J	10	250	630	0.25 U	1900	1900	170	6.69E+07	2.08E+08	ND	1.10E+07	6.15	-224.3	14.98	8026	0
	6/23/09	9 J	30000	4500	11 J	20 J	4 J	11	310	640	0.25 U	1900	1900	190	8.56E+06	1.30E+07	ND	2.00E+06	6.51	-58.4	0.9	8030	2.34
	10/13/09	250 U	35000	10000	250 U	250 U	5	10	650	630	0.25 U	1800	2100	91	3.50E+07	2.51E+07	ND	3.70E+06	6.36	12	1.16	7.904	>3.3
PMW-4 Zone 2	4/24/08	130 U	17000	130 U	130 U	130 U	5 U	5 U	50	NS	NS	NS	NS	NS	NS	NS	NS	NS	7.05	41.5	0.94	13331	0
	11/4/08	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	6.85	-32.7	1.48	15990	NM
PMW-4 Zone 3	4/24/08	16 J	8500	85	43 J	63 U	5 U	5 U	89	820	0.5 U	5600	3100	79	ND	NS	NS	NS	6.72	42.1	0.64	17019	0
	11/4/08	12 J	4600	96	40	13 U	5 U	5 U	75	730	0.5 U	5100	2200	53	ND	ND	ND	ND	6.75	50.8	0.8	14850	0.1
	4/28/09	33 J	3400	41 J	50 U	50 U	5 U	3 J	88	2100	0.1 U	5000	2100	2000	ND	ND	ND	ND	6.26	-37.7	3.17	15790	3.16
	6/23/09	16	2000	22	8.8 J	13 U	5 U	1 J	51	3000	0.5 U	3900	1100	2000	2.70E+04*	2.4E+04*	ND	5.1E+03*	6.51	-144.9	0.4	13430	2.79
	10/13/09	19	2600	29	8.7 J	5.3 J	5 U	4 J	270	2700	0.5 U	3900	1400	2400	1.03E+03*	7.12E+02*	ND	3.0E+03*	6.32	-62	0.74	12770	>3.3
PMW-4 Zone 4	4/24/08	16 J	8900	77	42 J	50 U	5 U	5 U	190	810	0.5 U	5000	3800	67	ND	NS	NS	NS	6.65	37.8	0.99	16058	0
	11/4/08	21	6300	86	27	13 U	5 U	5 U	130	820	0.5 U	4400	3000	57	ND	ND	ND	ND	6.73	50.8	1.27	14180	0.12
	4/28/09	30 Jb	7900	57	12 J	50 U	5 U	4 J	120	850	0.1 U	4400	2900	55	ND	ND	ND	ND	6.44	-24.7	4.11	13840	3.3
	6/23/09	18 J	6700	59	15 J	50 U	5 U	3 J	110	970	1 U	4300	2800	99	ND	ND	ND	ND	6.71	-81	0.89	13320	0.76
	10/15/09	14 J	7400	50	50 U	50 U	5 U	2 J	200	2000	0.5 U	3800	1900	910	ND	ND	ND	ND	6.39	-55.6	1.09	12.07	>3.3
PMW-4 Zone 5	4/24/08	1.9 J	990	6.7 J	1.6 J	7.1 U	5 U	5 U	110	NS	NS	NS	NS	NS	NS	NS	NS	NS	7.24	-61	1.02	13894	0.53
PMW-5 Zone 1	4/24/08	420 U	57000	420 U	420 U	420 U	5 U	5 U	130	220	0.57	2100	1900	38	ND	NS	NS	NS	6.99	42.5	0.33	7842	0
	9/2/08	420 U	52000	420 U	420 U	420 U	5 U	6	170	280	0.79	2200	1900	32	ND	ND	ND	ND	6.71	125.4	9.15	7680	0
	10/16/08	71 U	41000	45 J	71 U	71 U	5 U	8	200	330	0.25 U	2200	1700	42	NS	NS	NS	NS	6.67	28.5	1.28	7858	0.01
	11/4/08	200 U	37000	91 J	200 U	200 U	5 U	10	270	360	0.25 U	2200	1700	44	ND	ND	ND	ND	6.94	387.4	1.46	7190	0
	1/27/09	13 J	37000	45 J	50 U	50 U	5 U	9	250	350	0.1 U	2100	1600	57	3.83E+05	9.81E+04	ND	1.11E+05	6.79	-23.7	0.91	7899	0.23
	2/23/09	360 U	40000	360 U	360 U	360 U	5 U	10	260	370	0.25 U	2200	1600	63	6.85E+05	2.52E+06	ND	5.57E+05	6.89	-179.1	1.31	6740	0
	3/30/09	360 U	39000	360 U	360 U	360 U	5 U	7	180	390	0.25 U	2100	1600	55	1.86E+05	8.31E+05	ND	6.32E+04	6.41	-269	1.28	7779	0.08
	4/28/09	360 U	44000	360 U	360 U	360 U	5 U	7	170	410	0.1 U	2100	1600	68	1.97E+05	9.35E+05	ND	3.51E+04	6.6	59.8	2.98	8366	0
	5/27/09	250 U	35000	82 J	250 U	250 U	5 U	8	200	460	0.25 U	2100	1600	70	4.32E+06	2.49E+06	ND	8.40E+05	6.59	-158.5	0.9	7207	0.03
	6/23/09	310 U	39000	380	310 U	310 U	5 U	8	210	440	0.25 U	2000	1500	93	1.55E+06	3.70E+06	ND	5.50E+05	6.87	-10.9	0.92	7258	0
	10/7/09	200 U	23000	10000	200 U	450	10	8	830	640	0.25 U	2000	1500	100	1.43E+08	9.35E+07	ND	1.50E+07	6.27	-21.7	0.99	6.769	1.57
	10/7/2009-K	200 U	24000	11000	200 U	490	10	7	800	650	0.25 U	2000	1500	100	2.46E+08	2.21E+08	ND	4.10E+07					
PMW-5 Zone 2	4/24/08	100 U	13000	75 J	54 J	100 U	5 U	5 U	62	610	0.5 U	5700	3000	100	ND	NS	NS	NS	6.96	52	0.61	15992	0
	11/4/08	15	6100	86	43	13 U	5 U	5 U	57	950	0.5 U	6000	3100	95	ND	ND	ND	ND	6.89	127.5	1.67	16730	0.09
	4/28/09	20 J b	7100	56	31 J	50 U	5 U	2 J	69	1400	0.1 U	5900	2600	1000	ND	ND	ND	ND	6.56	-37.5	1.94	12740	3.3
	6/23/09	12 J	4600	69	26 J	42 U	5 U	2 J	61	1900	1 U	5000	1900	2200	ND	ND	ND	ND	6.61	-82.6	0.94	16230	1.56
	10/13/09	42 U	6700	220	23 J	42 U	5 U	2 J	67	2500	1 U	4600	1500	2300	3.32E+03*	1.38E+03*	ND	8.2E+02*	6.33	-98.7	0.65	1373	>3.3
PMW-5 Zone 3	4/24/08	83 U	11000	90	32 J	83 U	5 U	5 U	74	750	0.5 U	5800	3100	87	ND	NS	NS	NS	6.82	21.1	0.53	16173	0.015
	11/4/08	12 J	9100	72	34	25 U	5 U	5 U	83	890	0.5 U	5700	2900	83	ND	ND	ND	ND	6.82	66.8	1.02	15380	0.7
	4/28/09	41 J	6900	67	20 J	50 U	5 U	1 J	49	1100	1 U	5400	2600	NA	ND	ND	ND	ND	6.57	-22.2	0.57	15700	2.21
	6/23/09	42 U	5600	53	13 J	42 U	5 U	1 J	36	1200	1 U	5100	3000	430	ND	ND	ND	ND	6.7	-49.6	0.36	15010	3
	10/13/09	42 U	6900	72	42 U	42 U	5 U	2 J	71	1400	1 U	5300	2500	360	ND	ND	ND	ND	6.38	-45.9	1.46	14140	>3.3
PMW-5 Zone 4	4/24/08	31 U	5000	19 J	31 U	31 U	5 U	5 U	16	NS	NS	NS	NS	NS	NS	NS	NS	NS	7.41	-25.1	1.28	11794	0.76
PMW-6	4/22/08	31 U	11000	51	14 J	31 U	5 U	5 U	170	530	0.1 J	3000	3000	56	ND	NS	NS	NS	6.53	345	0.98	12976	0
	9/5/08	68 J	12000	86	21 J	83 U	5 U	5 U	96	600	0.5 U	3200	3100	51	9.65E+02	6.77E+01	3.71E+01	ND	5.82	247.5	3.96	1106	0
	10/15/08	50 U	9500	86	19 J	50 U	5 U	5 U	110	600	0.25 U	3000	2800	61	NS	NS	NS	NS	6.4	34	1.8	12530	0.06
	10/15/2008 - K	10 J	10000	77	21	20 U	5 U	5 U	100	610	0.25 U	3100	2700	57	NS	NS	NS	NS					
	11/3/08	50 U	9700	80	14 J	50 U	5 U	5 U	130	660	0.1 U	3300	2900	78	ND	ND	ND	ND	6.64	-45.2	0.75	11060	0.99
	1/27/09	50 U	7400	600	50 U	50 U	5 U	5 U	68	740	0.1 U	2600	2900	120	ND	ND	ND	ND	6.61	-105.2	0.5	12770	2.86
	2/23/09	17 U	2100	800	7.6 J	54	5 U	5 U	98	1300	0.1 U	1900	1100	1100	2.76E+07	1.14E+08	ND	5.79E+06	6.5	-328.4	0.44	7552	3.03
	3/30/09	5 J	1000	350	4.9 J	350	380	5 U	55	2400	0.5 U	2100	2000	1600	1.71E+09	5.90E+09	ND	6.11E+08	6.47	-322.4	2.92	11900	0.67
	4/27/09	4.2 J	740	360	8.2	410	310	2 J	72	3100	0.035	1500	1700	2300	5.62E+08	3.61E+09	ND	1.72E+08	6.46	-336.4	5.98	7721	0.03
	5/27/09	2.7 J	820	310	4.9 J	340	290	2 J	260	3100	0.25	790	1300	3400	1.00E+09	9.54E+08	ND	2.60E+08	6.23	-330.6	12.58	8591	0.35
	6/22/09	3 J	790	460	6.4	120	190	5 U	1100	3200	0.06 J	600	1400	3400	1.59E+09	3.80E+09	ND	4.60E+08	6.72	-335.3	0.54	9043	0
	6/22/2009-K	3.1 J	910	490	7	130	170	5 U	900	3100	0.13	760	1500	3200	9.64E+08	2.00E+09	ND	2.40E+08					
	10/15/09	5.7	760	690	11	470	220	1 J	2300	1900	0.25 U	2000	1800	400	4.22E+08	2.44E+08	ND	4.90E+07	5.54	-328.7	0.98	9763	NM
	4/22/08	31 U	17000	76	21 J	31 U	5 U	9	210	540	0.03 J	3000	3200	50	ND	NS	NS	NS	6.66	301	0.96	13572	0

PASSIVE CELL Monitoring Data Summary NAVFAC Naval Weapons Station - Site 70		Tetrachloroethene	Trichloroethene	cis-1,2-Dichloroethene	trans-1,2-Dichloroethene	Vinyl Chloride	Ethene	Ethane	Methane	Alkalinity	Nitrate	Sulfate	Chloride	Chemical Oxygen Demand	Dehalococcoides - 16S rRNA	Dehalococcoides - tceA	Dehalococcoides - bvcA	Dehalococcoides - vcrA	pH	ORP (Mv)	DO (mg/L)	Conductivity (µmhos/cm)	Ferrous Iron
	Units:	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	mg/L	mg/L	mg/L	mg/L	mg/L	gene copies/L					mV	mg/L		mg/L
PMW-7	9/5/08	27 J	15000	78 J	28 J	83 U	5 U	5 U	150	600	0.5 U	3500	3200	53	1.51E+03	1.75E+02	2.51E+01	ND	6.11	310.2	1.23	1274	0
	10/15/08	9.6 J	10000	57	13 J	25 U	5 U	5 U	110	1200	0.25 U	3000	2400	1300	NS	NS	NS	NS	6.26	-221.9	0.81	12010	NM
	11/3/08	50 U	9600	59	50 U	50 U	5 U	5 U	140	1100	0.1 U	2600	2600	1100	ND	ND	ND	ND	6.49	-240.9	0.5	11990	1.94
	1/27/09	50 U	5800	33 J	50 U	50 U	5 U	5 U	96	2300	0.1 U	2800	2200	1700	6.15E+03	1.02E+03	ND	2.19E+03	6.6	-287.9	0.44	13.3	0.4
	2/23/09	50 U	6500	44 J	50 U	50 U	5 U	5 U	110	2800	0.1 U	2800	1900	2700	ND	ND	ND	ND	6.46	-327.4	0.52	12848	0.66
	2/23/2009 - K	31 U	6700	46	31 U	31 U	5 U	5 U	110	2600	0.1 U	2900	2000	2600	ND	ND	ND	ND					
	3/30/09	50 U	8600	58	18 J	50 U	5 U	5 U	100	2300	0.1 U	2900	2400	1500	5.78E+03	2.29E+04	ND	1.88E+03	6.42	-324.8	6.58	13520	1.56
	4/27/09	50 U	5800	1700	16 J	50 U	5 U	4 J	120	2100	0.1 U	3300	2500	1500	2.04E+03	1.43E+04	ND	3.83E+02	6.31	-222.4	0.47	8383	3.3
	5/27/09	25 U	2900	1300	9.2 J	120	5 U	3 J	96	3300	0.5 U	2200	1600	3200	3.83E+08	3.04E+08	ND	2.50E+06	6.28	-322.5	12.58	11720	0.57
	6/22/09	4.2 U	190	96	2.4 J	590	28	1 J	47	4400	0.1 U	650	820	5400	1.06E+09	2.20E+09	ND	7.10E+07	6.75	-320.8	0.66	9510	0
	10/15/09	5 U	120	41	4.2 J	67	81	0.5 J	2600	5200	0.1 U	320	710	8400	2.63E+08	2.22E+08	ND	3.40E+07	7.01	-340.7	1.49	9644	0
PMW-8	4/23/08	8 J	15000	120	10 J	17 U	5 U	34	430	590	0.5 U	2400	2400	46	ND	NS	NS	NS	6.64	189.5	0.96	10876	0
	9/3/08	71 U	12000	100	71 U	71 U	5 U	6	140	780	0.25 U	2300	1800	660	ND	ND	ND	ND	6.01	-141.7	1.92	7889	0
	10/15/08	17 U	8300	58	8.8 J	17 U	5 U	6	120	1400	0.25 U	2000	1600	1600	NS	NS	NS	NS	6.22	-243	0.68	8568	>3.3
	11/3/08	83 U	8500	69 J	83 U	83 U	5 U	7	150	1400	0.1 U	1900	1600	1400	ND	ND	ND	ND	6.42	-297.8	0.31	8123	3.07
	1/27/09	17 U	1300	2700	3.7 J	17 U	5 U	8	160	2000	0.1 U	1500	1500	1300	ND	ND	ND	ND	6.55	-257	0.36	9157	0.85
	2/23/09	17 U	1100	4500	4.4 J	17 U	5 U	9	190	1500	0.1 U	1900	1700	420	7.05E+04	1.50E+05	ND	3.28E+04	6.35	-268.4	2.22	8445	1.49
	3/30/09	10 U	1700	1400	3 J	140	150	8	170	1900	0.1 U	1500	1500	1400	1.40E+08	6.59E+08	ND	6.09E+07	6.45	-241.7	0.24	8802	1.03
	4/27/09	6.1 J	1500	470	2.7 J	420	330	11	350	2000	0.1 U	1400	1500	1600	1.61E+08	1.08E+09	ND	5.11E+07	6.32	-313.9	15.41	8485	0.36
	5/27/09	10 U	1300	330	3.3 J	260	410	12	1100	2300	0.25 U	1100	1300	2400	4.49E+08	7.42E+08	ND	1.80E+08	6.2	-323	17.02	7700	1.38
	6/22/09	5 U	710	180	2.9 J	250	350	10	1300	2700	0.1 U	760	1100	3500	2.16E+09	5.50E+09	ND	6.90E+08	6.6	-353.1	0.56	7496	1.46
	10/7/09	1.8	72	76	6.3	100	250	9	2300	3200	0.1 U	33	860	3200	7.06E+07	5.39E+07	ND	1.20E+07	6.52	-313.8	0.2	6622	1
PMW-9	4/23/08	6.3 U	840	18	6.3 U	6.3 U	5 U	48	2800	990	0.01 J	1100	160	16	ND	NS	NS	NS	6.75	35.2	0.57	4114	0
	9/3/08	3.5 J	2000	35	6.3 U	6.3 U	5 U	6	460	810	0.1 U	2700	400	13	ND	ND	ND	ND	6.11	-88.4	1.85	5543	0
	10/15/08	4.2 U	1800	34	1.3 J	4.2 U	5 U	5	360	810	0.25 U	2800	400	13	NS	NS	NS	NS	6.35	47.7	0.98	6034	0
	11/3/08	17 U	1500	31	17 U	17 U	5 U	5	370	800	0.1 U	3000	440	13	ND	ND	ND	ND	6.52	115.7	0.84	6066	0
	1/27/09	0.7 J	350	7	2 U	2 U	5 U	27	770	1000	0.1 U	1700	220	19	ND	ND	ND	ND	6.71	-96.4	0.63	4993	0.48
	2/23/09	0.3 J	96	5.8	0.1 J	0.5 U	5 U	48	1500	1100	0.1 U	950	120	17	ND	ND	ND	1.31E+03	6.72	-222.1	4.65	3098	0.25
	3/30/09	0.8 J	240	160	0.4 J	0.2 J	5 U	20	640	1100	0.33	1200	120	15	ND	ND	ND	ND	6.53	-102	0.82	3562	2.88
	4/27/09	1.4 J	110	270	0.6 J	11	4 J	20	640	1500	0.1 U	1600	290	320	9.79E+05	5.18E+06	ND	1.79E+05	6.43	-295.2	10.54	5846	0.12
	5/27/09	0.8 J	100	200	1.2 J	80	100	39	2200	2200	0.25 U	1300	480	720	2.48E+08	1.86E+08	ND	5.20E+07	6.3	-305.8	2.63	5772	0.62
	6/22/09	0.2 J	19	19	1.1	37	110	26	3000	2100	0.1 J	960	580	400	2.80E+07	5.60E+07	ND	8.00E+06	6.8	-290.2	0.6	5921	0
	10/7/09	0.2 J	45	14	1.2	25	66	16	6600	1700	0.25 U	2500	1100	120	1.12E+07	9.83E+06	ND	1.90E+06	6.67	-282.4	0.56	7605	0.05

Notes:
K - Duplicate sample
J - estimated value
U - nondetect (detection limit is indicated)
NA - not analyzed
ND - not detected
NS - not sampled
* - indicates that the value presented is below the reporting limit.

µmhos/cm - micromhos per centimeter
µg/L - mcrograms per liter
mg/L - milligrams per liter
mV - millivolts
ORP - oxidation reduction potential
DO - dissolved oxygen
> - greater than
NM - not measured

February 2009	TCE (ppb)	$\delta^{13}C$	cDCE	$\delta^{13}C$	VC	$\delta^{13}C$	Ethene	$\delta^{13}C$ eth	2-butanone	chloroform	chlor/DCE
SB-AEW	21000	-24.3	1100	-26.8							
SB-AMW1-25'	27000		7000	-24.6							
SB-AMW2-25'	97		9500	-22.9	940	-43.0				75	0.01
SB-AMW3-Z1	6000	-24.5	2300	-24.5	210					55	0.02
SB-AMW4-Z1	310	-17.9	6700	-36.5	2900		59				
SB-AMW5-Z1	5800	-23.7	2800	-25.0	57					100	0.04
SB-AMW6-25'	130000	-23.9		-31.7		-28.5					
SB-PIW1-25'	42		4	-27.0						120	32.43
SB-PIW2-25'	12	-26.1	3	-27.9	23				110	3	1.00
SB-PIW3-25'	2	-23.5	1	-25.4	5				160		
SB-PMW1-25'	1700	-28.0	79							74	0.94
SB-PMW2-25'	1800		43								
SB-PMW3-Z1	41000	-23.3									
SB-PMW4-Z1	41000	-23.3									
SB-PMW5-Z1	40000	-24.6									
SB-PMW6-25'	2100	-23.3	800	-19.2	54					280	0.35
SB-PMW7-25'	6500									690	
SB-PMW8-25'	1100	-20.0	4500	-25.2						30	0.01
SB-PMW9-25'	96	-22.6	6								
Average of all		-23.5		-26.4		-35.8					
AEW/AMW Ave		-22.9		-27.4		-35.8					
PIW/PMW Ave		-23.9		-24.9							

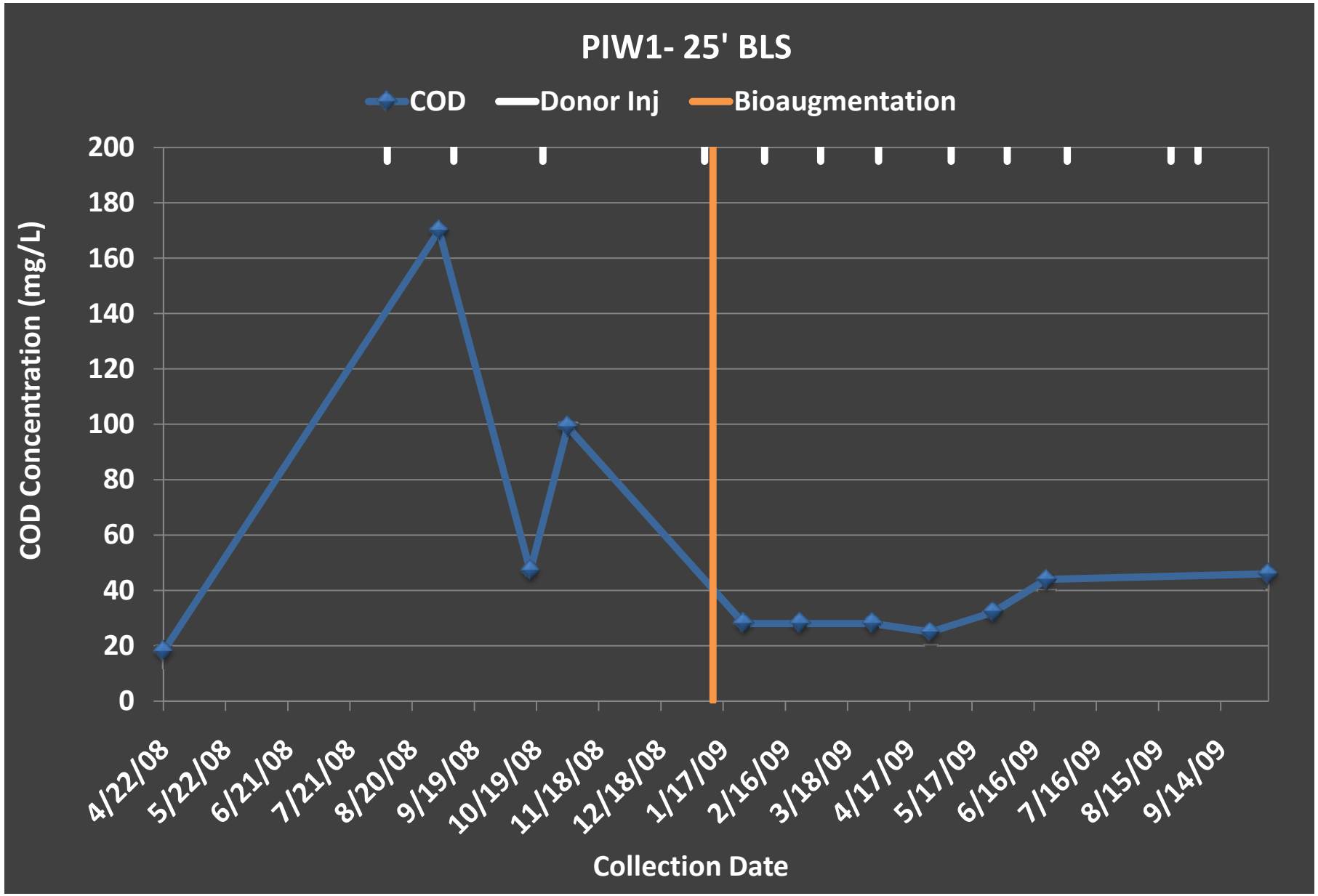
April 2009	TCE (ppb)	$\delta^{13}C$	cDCE	$\delta^{13}C$	VC	$\delta^{13}C$	Ethene	$\delta^{13}C$ eth	2-butanone	chloroform	chlor/DCE
SB-AEW	6500	-22.7	330	-24.9							
SB-AMW1-25'	880	-22.2	3000	-15.4	1100	-35.4	17				
SB-AMW2-25'	540	-9.9	1700		6900	-30.2	16				
SB-AMW3-Z1	1200	-22.5	2700	-15.9	3900	-26.2	58				
SB-AMW3-Z2	780	-22.6	6500	-13.9	1900	-40.2	13			99	0.02
SB-AMW3-Z3	130		11000		190	-47.0					
SB-AMW4-Z1	250	-16.8	4100	-9.6	5400	-32.5	14				
SB-AMW4-Z2	81		5500	-6.0	8100	-33.0	12				
SB-AMW4-Z3	4200	-21.9	7400	-19.4	2000	-37.8					
SB-AMW5-Z1	2600	-21.5	5500	-19.3	3500	-31.8	19			72	0.01
SB-AMW5-Z2	81		9000	-11.7	5200	-40.0	40				
SB-AMW5-Z3	1900	-21.5	4200	-21.8	170	-39.9				77	0.02
SB-AMW6-25'	70000	-22.9	1100	-25.1						120	0.11
SB-PIW1-25'	26		23		4			-17.2		11	0.48
SB-PIW2-25'	44	-23.1			6				180		
SB-PIW3-25'			1		6	-28.0			170		
SB-PMW1-25'	1400	-28.3	65							58	0.89
SB-PMW2-25'	280	-21.7	7							140	21.54
SB-PMW3-Z1	45000	-21.9	260							48	0.18
SB-PMW4-Z1	42000	-22.0	520							220	0.42
SB-PMW4-Z3	3400	-23.4	41							5600	136.59
SB-PMW4-Z4	7900	-23.5	57							3300	57.89
SB-PMW5-Z1	44000	-24.1								130	
SB-PMW5-Z2	7100	-24.0	56							2900	51.79
SB-PMW5-Z3	6900	-23.5	67							3800	56.72
SB-PMW6-25'	740	-17.9	360		410	-22.4	310	-27.5	42	230	0.64
SB-PMW7-25'	5800	-22.0	1700	-23.8					260	570	0.34
SB-PMW8-25'	1500	-15.5	470	-9.5	420	-14.4	330	-29.7		56	0.12
SB-PMW9-25'	110	-22.0	270	-22.8	11.0	-15.9					
Average of all		-21.6		-17.1		-31.6					
AEW/AMW Ave		-20.5		-16.6		-35.8					
PIW/PMW Ave		-22.4		-18.7		-20.2		-24.8			

June 2009	TCE (ppb)	$\delta^{13}C$	cDCE	$\delta^{13}C$	VC	$\delta^{13}C$	Ethene	$\delta^{13}C$ eth	2-butanone	chloroform	chlor/DCE
SB-AEW	8000	-24.4	920	-25.6		-37.2					
SB-AEW K	16000	-23.9	1900	-23.0							
SB-AMW1-25'	1900	-23.2	1200	-14.5	2800	-27.8	22				
SB-AMW2-25'	280	-5.2	440	6.8	6400	-26.8	33				
SB-AMW2-25' K	290	-4.3	430	6.6	6500	-26.1	34				
SB-AMW3-Z1	580	-21.9	690	-14.7	7000	-22.9	200				
SB-AMW3-Z2	520	-20.0	1400	-11.7	5500	-26.4	77				
SB-AMW3-Z3	87	-18.6	2000	-8.2	5300	-26.9	27				
SB-AMW4-Z1	150	-18.2	380	-4.8	7000	-26.9	110				
SB-AMW4-Z2					7600	-26.3	65				
SB-AMW4-Z3	1900	-22.2	3400	-16.4	4600	-27.4	11				
SB-AMW5-Z1	1100	-22.3	1500	-15.5	6000	-25.2	86				
SB-AMW5-Z2	91	-8.6	290	4.0	6900	-27.0	63				
SB-AMW6-25'	53000	-23.5	3600	-19.8	310	-27.3					
SB-PIW1-25'	13		9		19	-19.3		-12.6			
SB-PIW2-25'	17		3		8						
SB-PIW3-25'	54		2		4						
SB-PMW1-25'	1400	-28.0	69	-30.5			6				
SB-PMW2-25'	4400	-23.4									
SB-PMW3-Z1	47000	-24.3	190		310						
SB-PMW3-Z2	1400	-24.1	11								
SB-PMW4-Z1	30000	-23.3	4500	-25.2							
SB-PMW4-Z3	2000	-24.2	22								
SB-PMW4-Z4	6700	-24.3	59								
SB-PMW5-Z1	39000	-24.6	380		310						
SB-PMW5-Z2	4600	-23.9	69								
SB-PMW5-Z3	5600	-24.6	53								
SB-PMW6-25'	790	-16.2	460	-20.5	120	-18.5	190	-21.0			
SB-PMW6-25' K	910	-16.9	490	-20.3	130	-20.6	170	-21.7			
SB-PMW7-25'	190	-8.7	96	1.3	590	-18.3	28	-34.1			
SB-PMW8-25'	710	-12.6	180	-7.3	250	-8.8	350	-26.5			
SB-PMW9-25'	19	-18.8	19		37	-4.2	110	-23.4			
Average of all		-19.8		-12.6		-23.4		-23.2			
AEW/AMW Ave		-18.2		-10.5		-27.2					
PIW/PMW Ave		-21.2		-17.1		-15.0		-23.2			

October 2009	TCE (ppb)	$\delta^{13}C$	cDCE	$\delta^{13}C$	VC	$\delta^{13}C$	Ethene	$\delta^{13}C$ eth	2-butanone	chloroform	chlor/DCE
SB-AEW		-24.2		-19.8		-30.0					
SB-AMW1-25'		-20.6		-18.2		-19.6		-44.2			
SB-AMW2-25'		-6.9		-21.2		-24.5					
SB-AMW3-Z1						-21.4					
SB-AMW3-Z2											
SB-AMW3-Z3						-23.6		-28.7			
SB-AMW4-Z1						-20.5		-40.4			
SB-AMW4-Z2						-20.3					
SB-AMW4-Z3						-22.1					
SB-AMW5-Z1		-23.4		-18.5		-23.8		-48.7			
SB-AMW5-Z2											
SB-AMW5-Z3											
SB-AMW6-25'		-23.9		-17.1		-27.5					
SB-PIW1-25'		-22.9		-21.8							
SB-PIW2-25'								-42.7			
SB-PIW3-25'								-45.8			
SB-PIW3-25' K								-53.6			
SB-PMW1-25'		-28.2									
SB-PMW2-25'		-23.5									
SB-PMW3-Z1		-24.4									
SB-PMW3-Z2		-23.2									
SB-PMW3-Z3		-24.4									
SB-PMW4-Z1		-23.3		-22.8							
SB-PMW4-Z3		-24.3									
SB-PMW4-Z4		-24.7									
SB-PMW5-Z1		-23.3		-22.2		-43.3					
SB-PMW5-Z1 K		-23.5		-23.1		-42.4					
SB-PMW5-Z2		-23.1									
SB-PMW5-Z3		-23.2									
SB-PMW6-25'		-17.7		-18.4		-19.8		-43.3			
SB-PMW7-25'											
SB-PMW8-25'		-19.2						-36.2			
SB-PMW9-25'								-40.3			
Average of all		-22.4		-20.3		-26.1		-42.4			
AEW/AMW Ave		-19.8		-19.0		-23.3		-40.5			
PIW/PMW Ave		-23.3		-21.7		-35.2		-43.7			

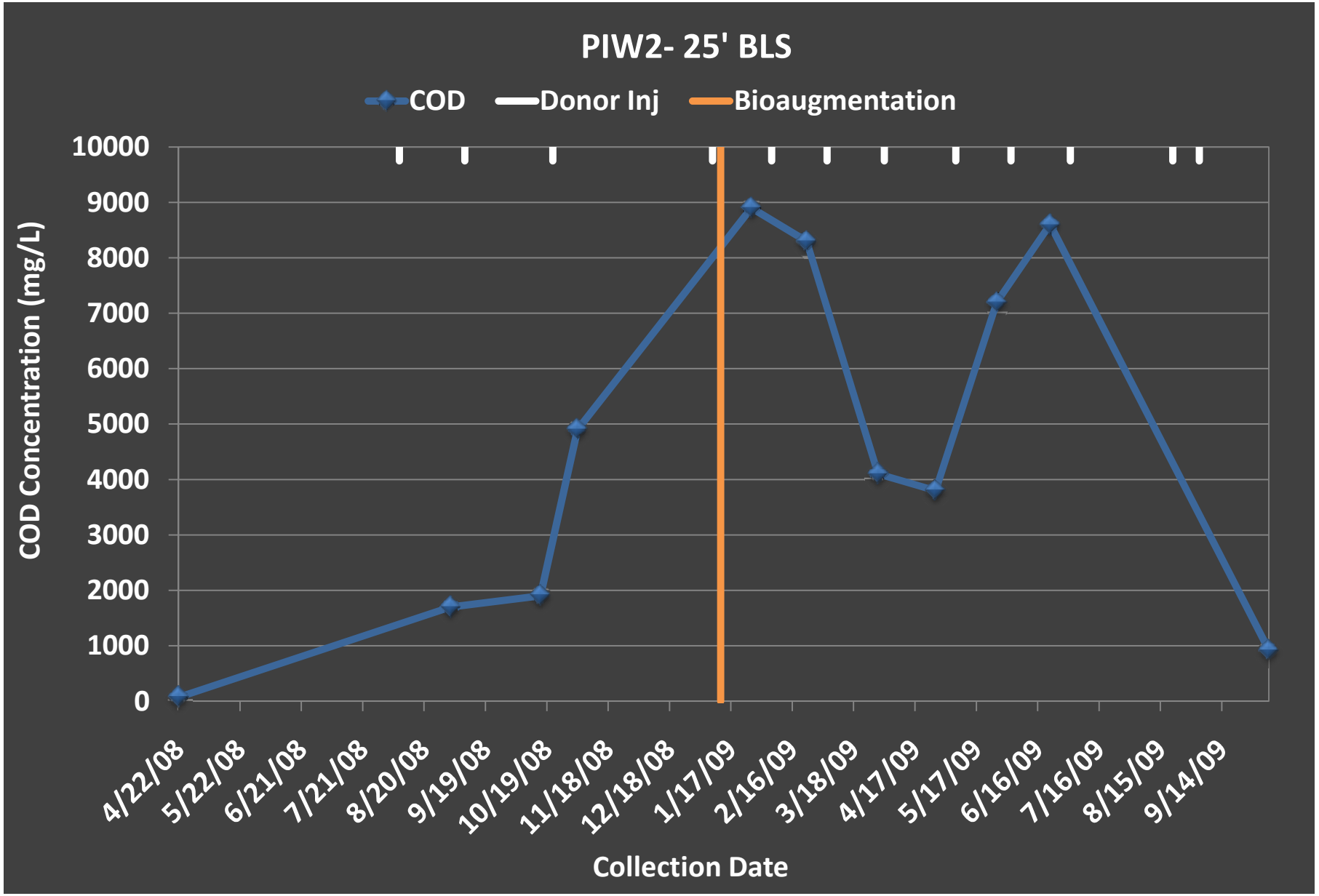
COD

Seal Beach
Groundwater Bioaugmentation



PIW1-25 ED, COD__Pas_Seal Beach_Oct 2009.xlsx

Seal Beach
Groundwater Bioaugmentation



PIW2-25 ED, COD__Pas_Seal Beach_Oct 2009.xlsx

Seal Beach
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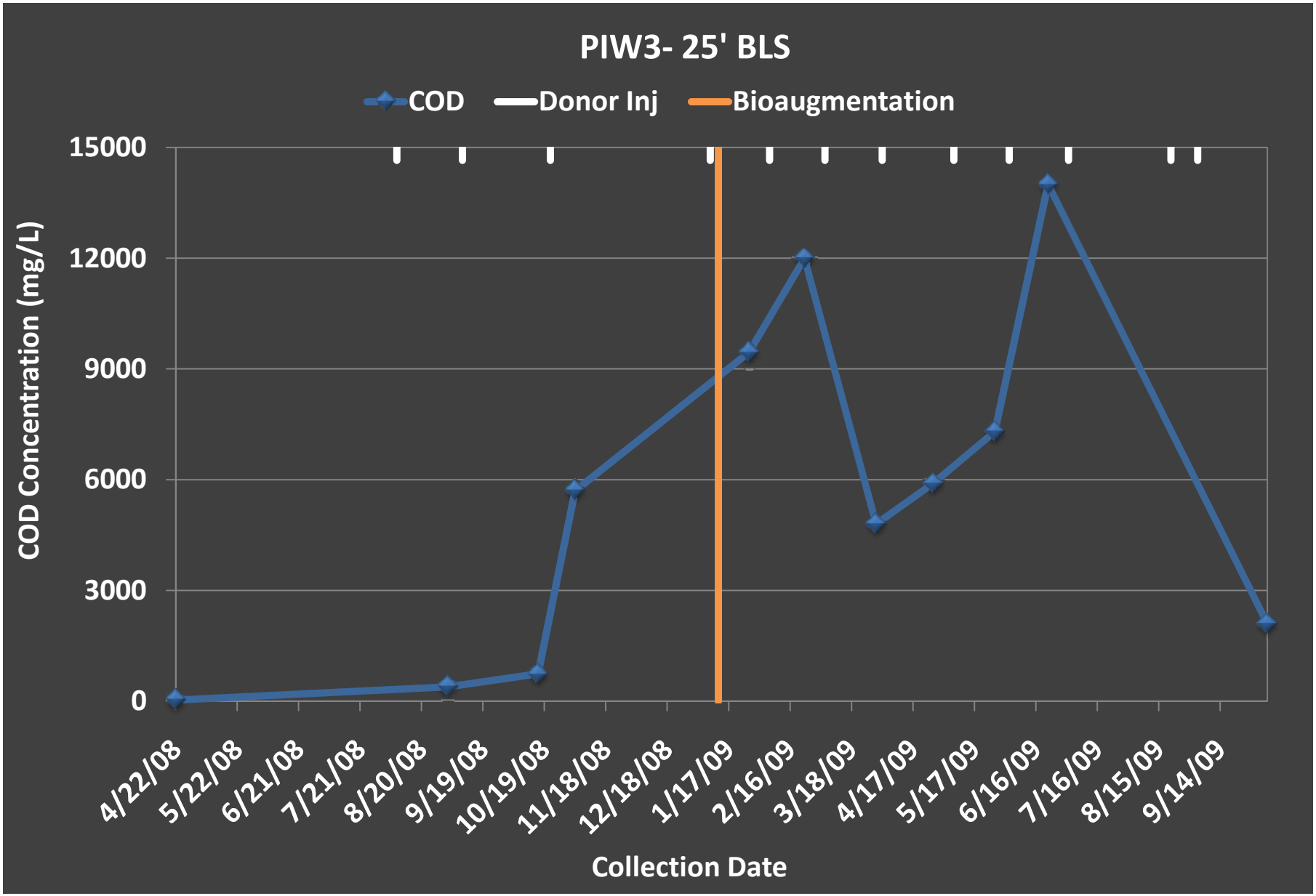

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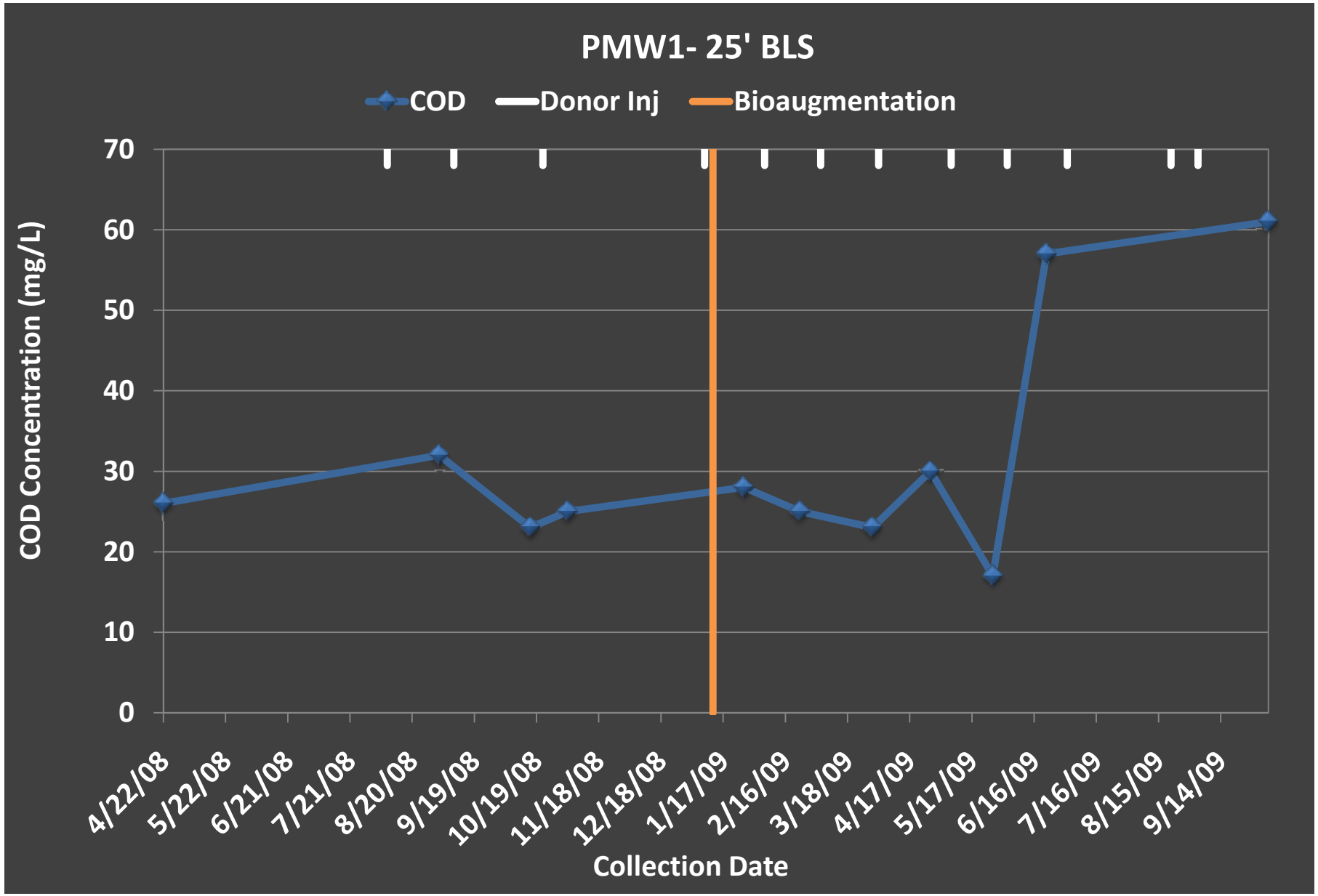
Seal Beach
Groundwater Bioaugmentation



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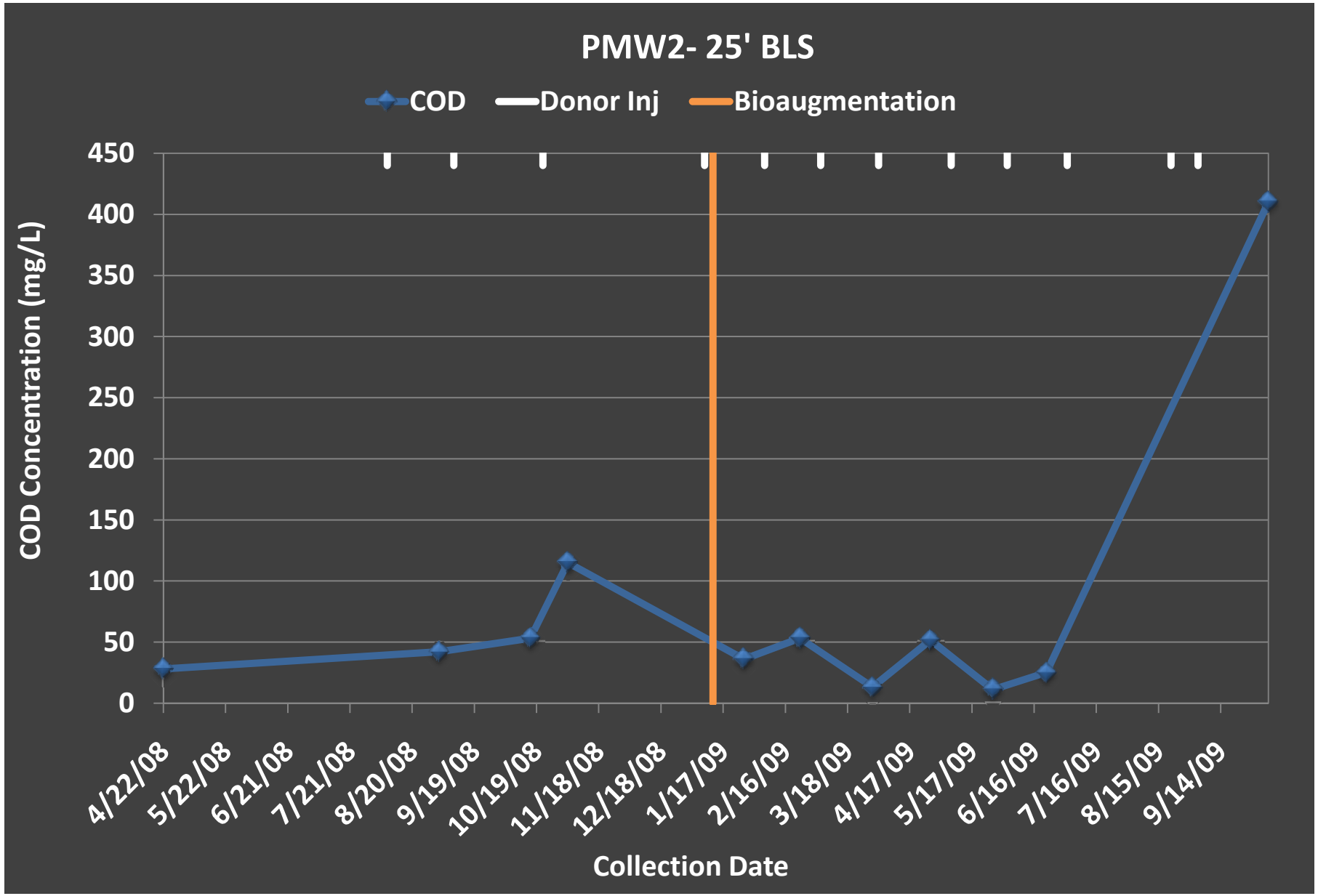

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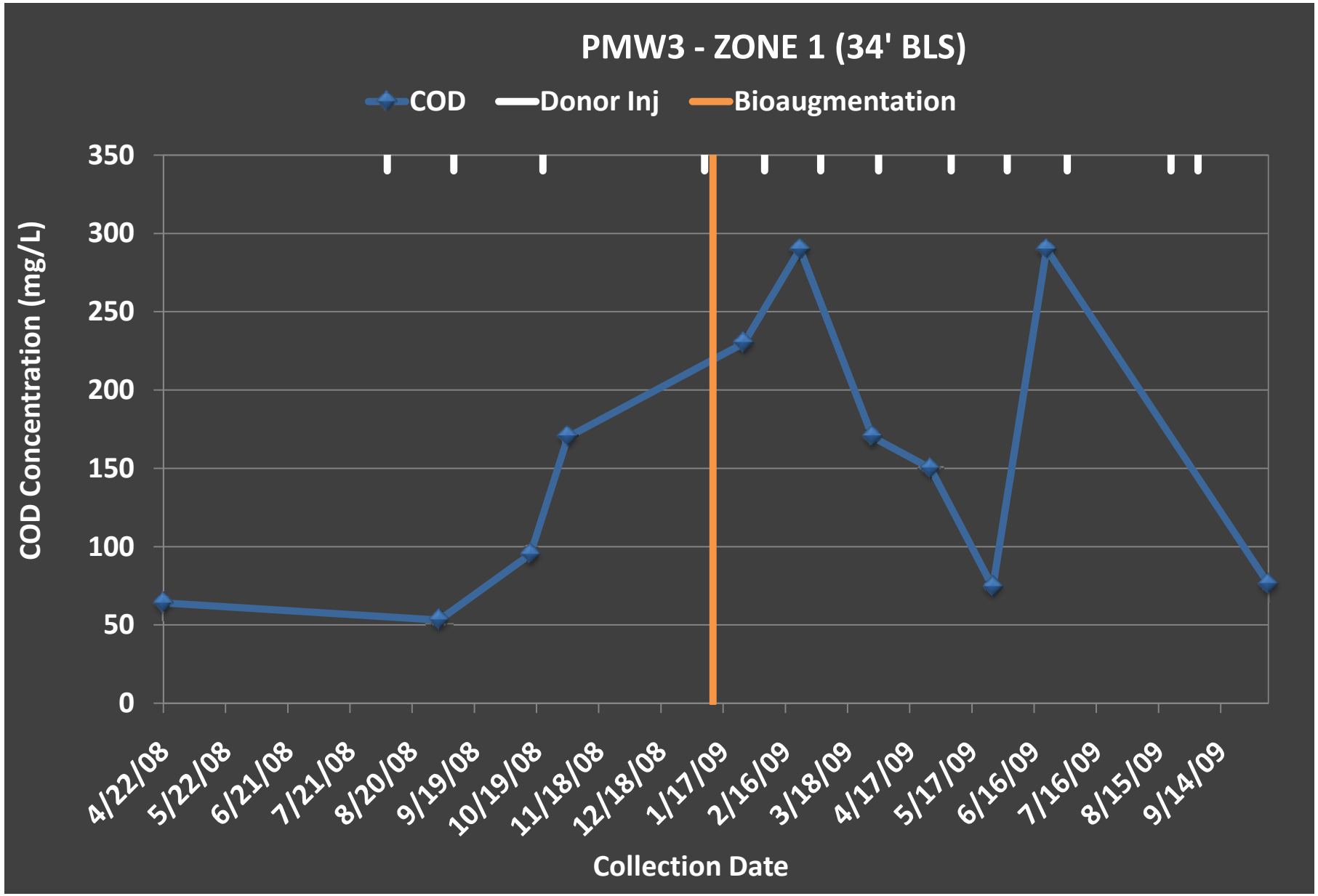

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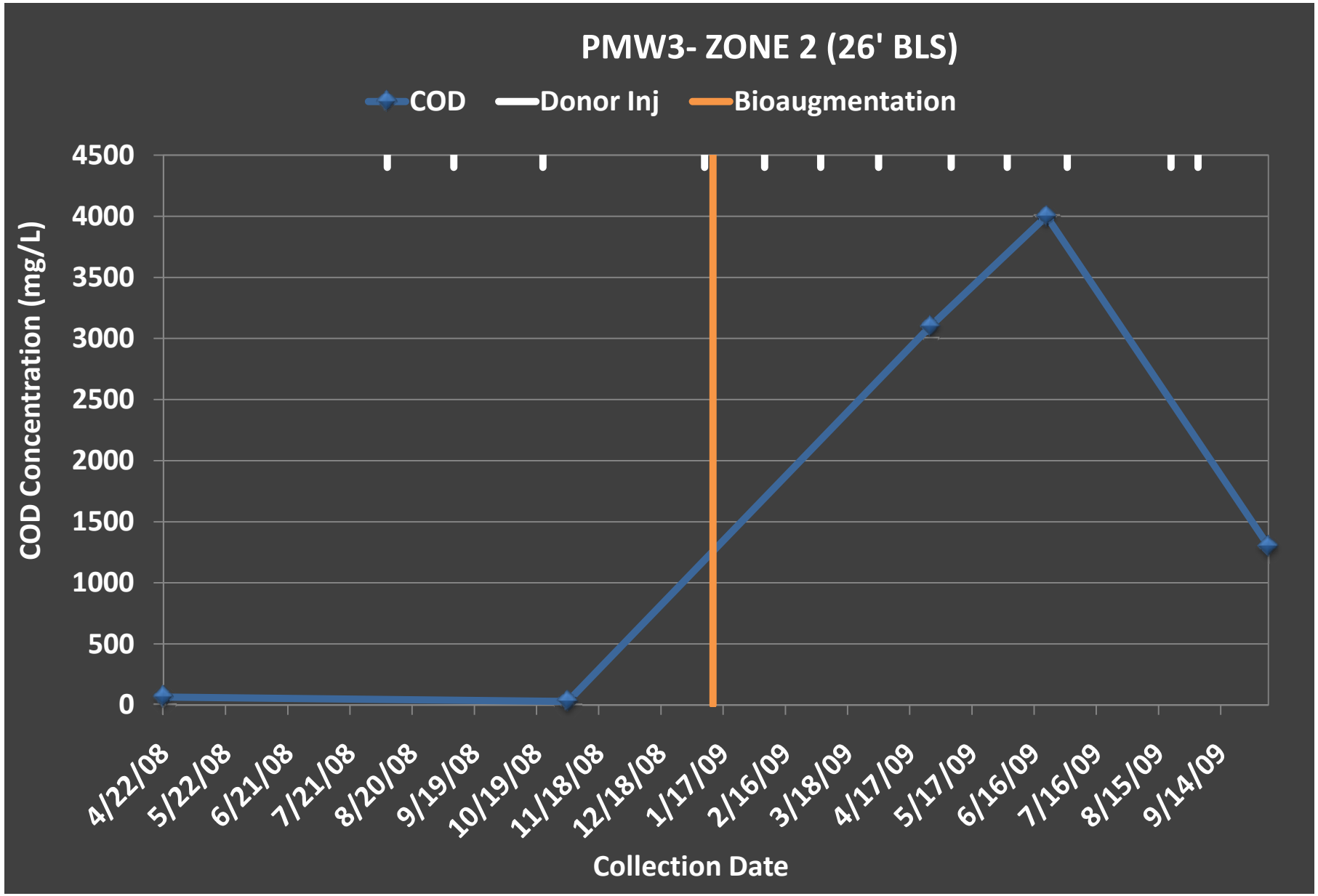

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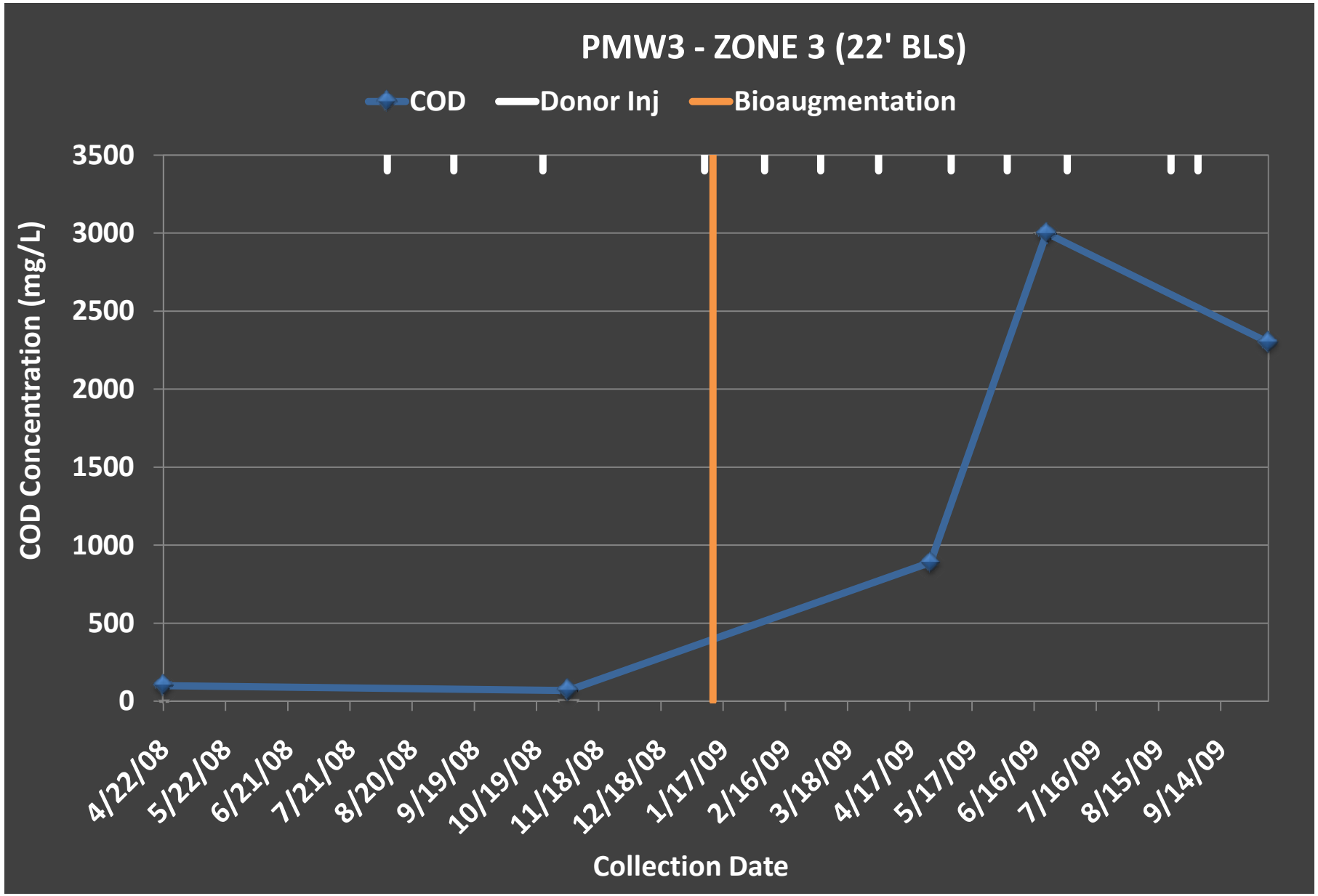

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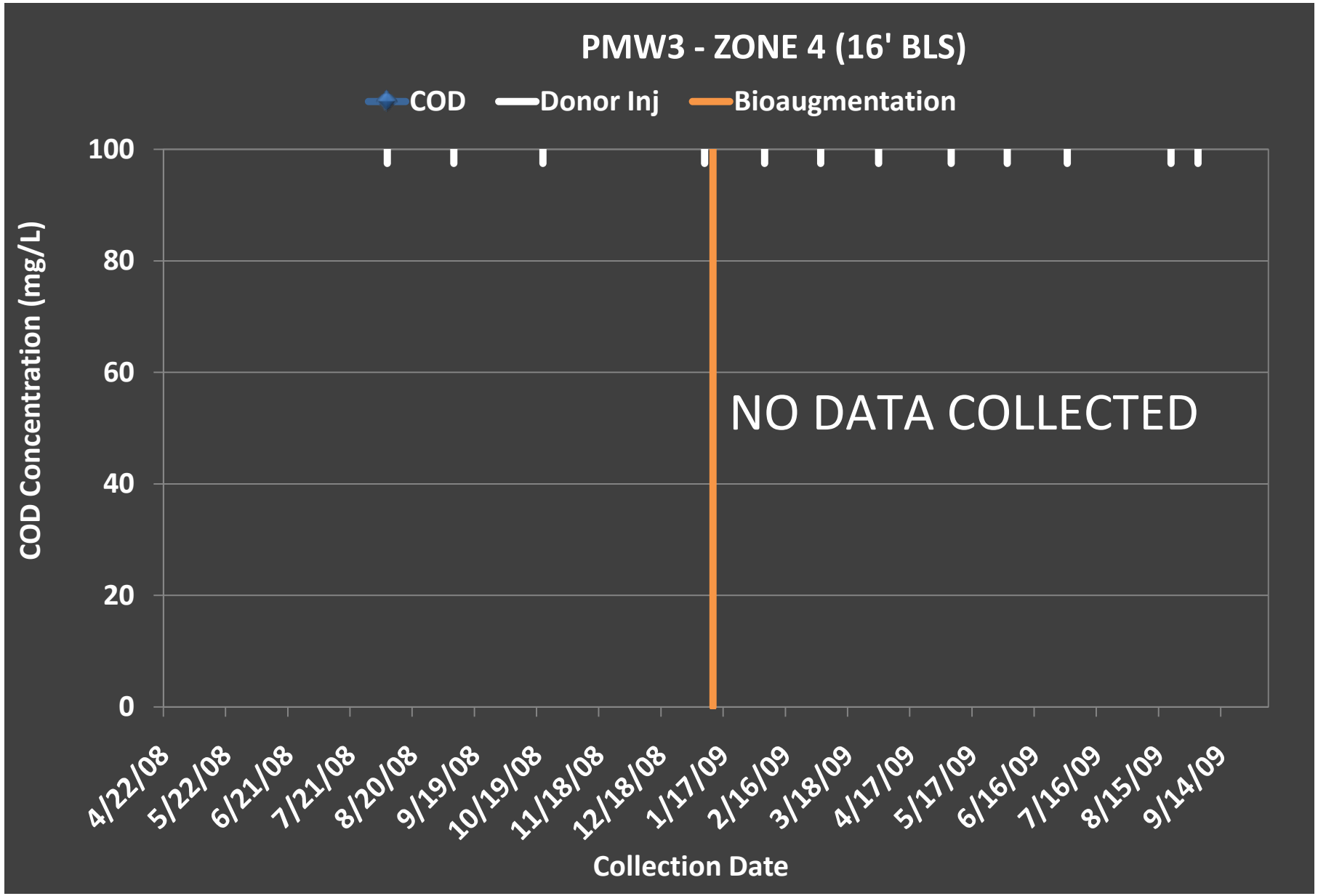

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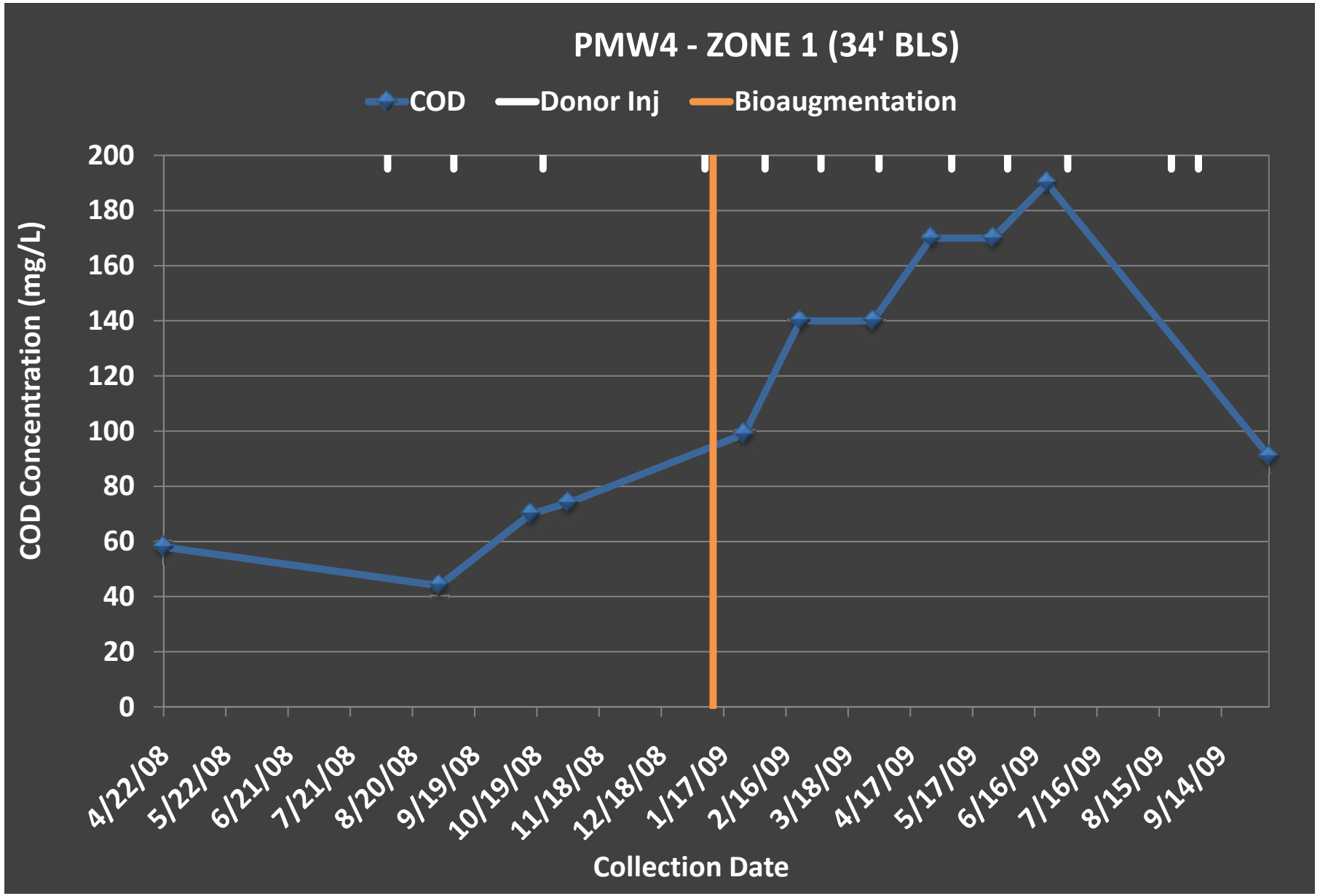

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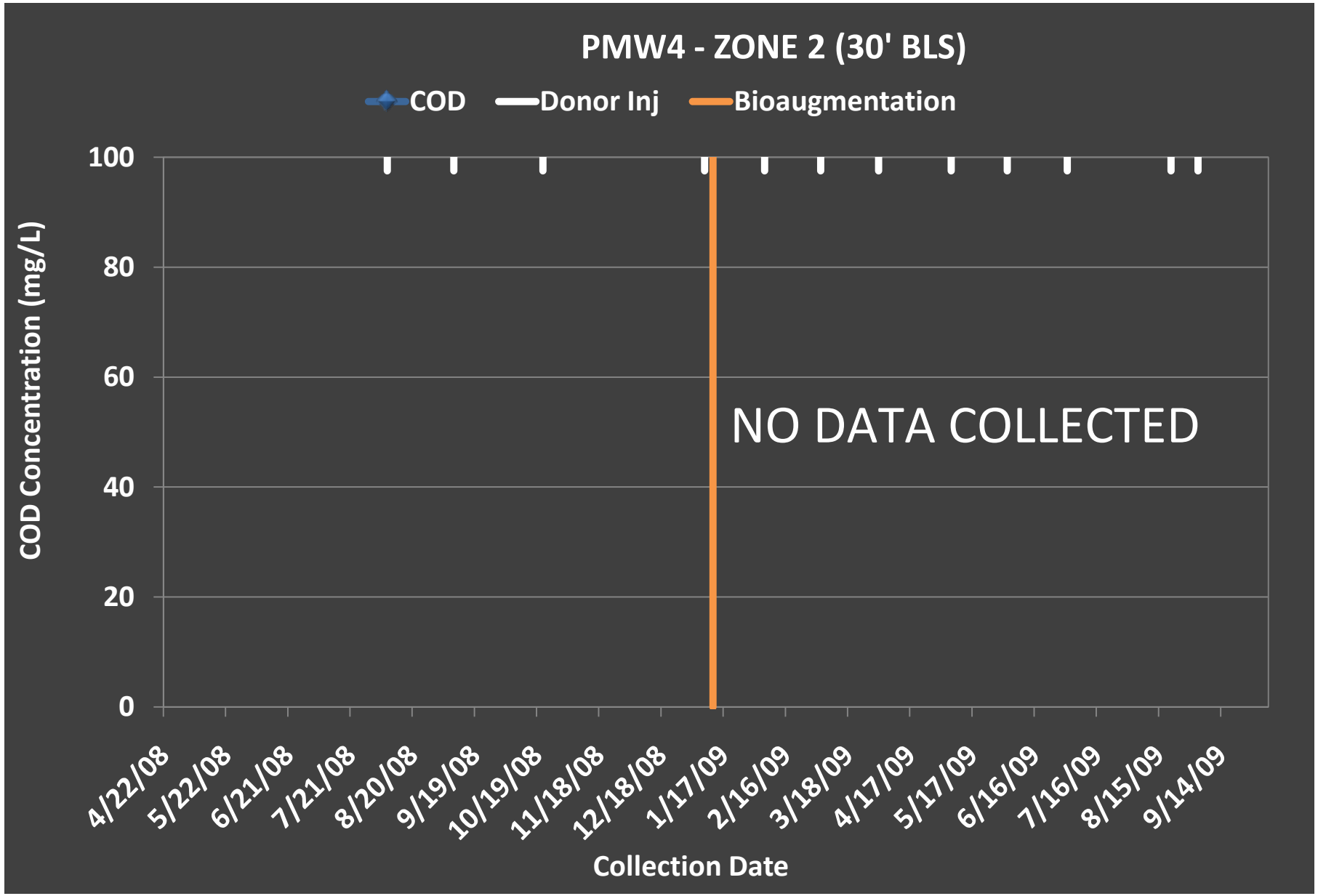

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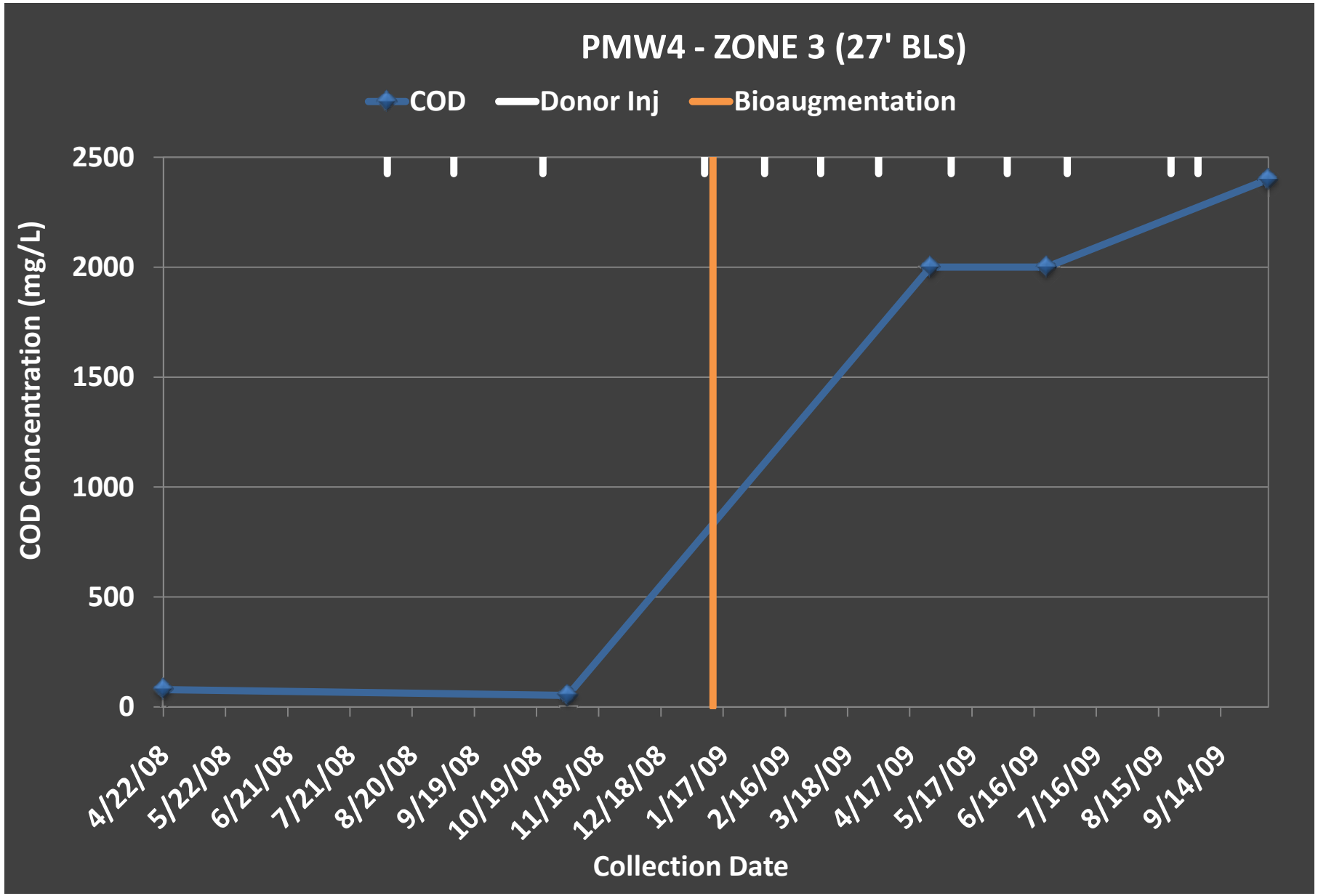

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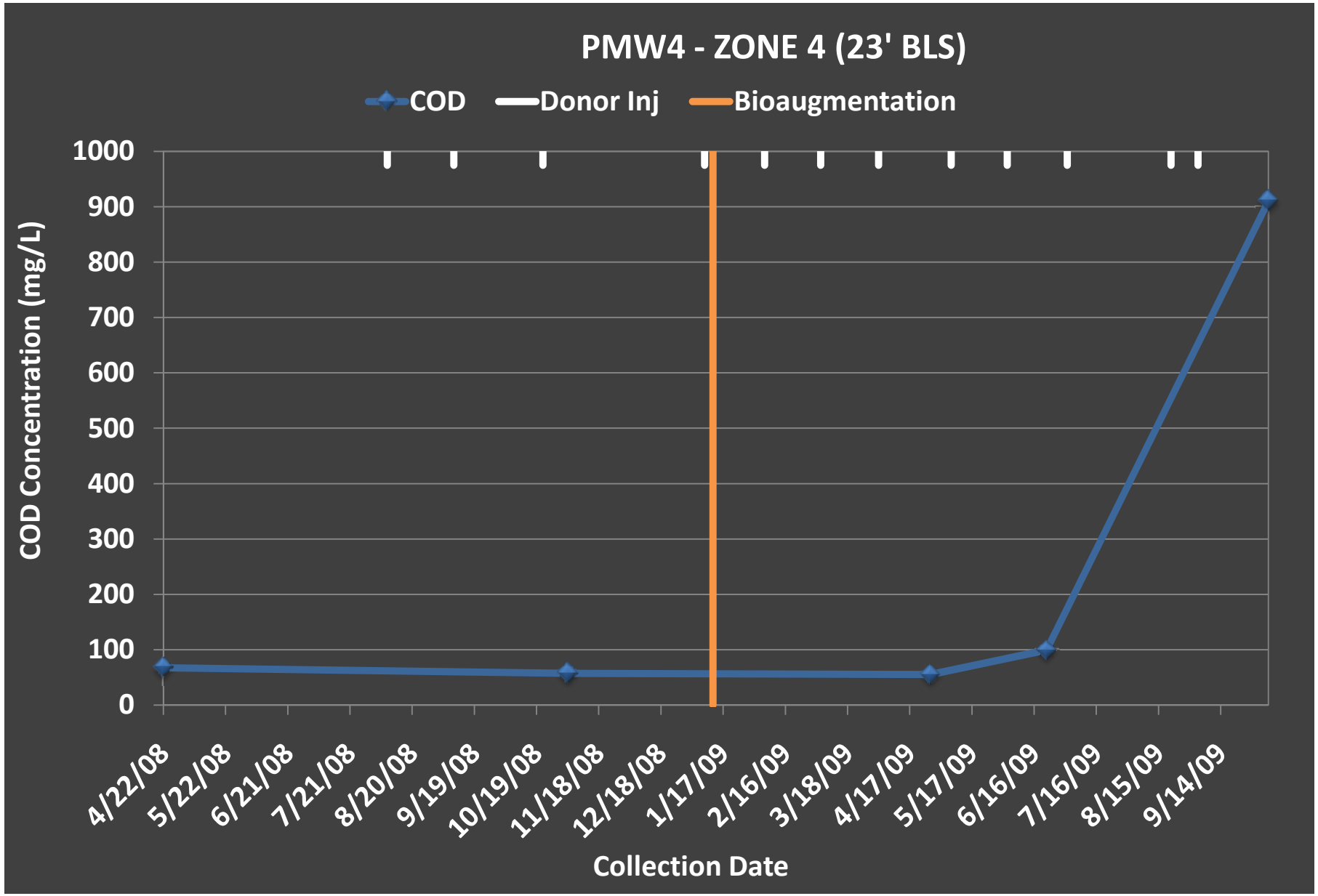

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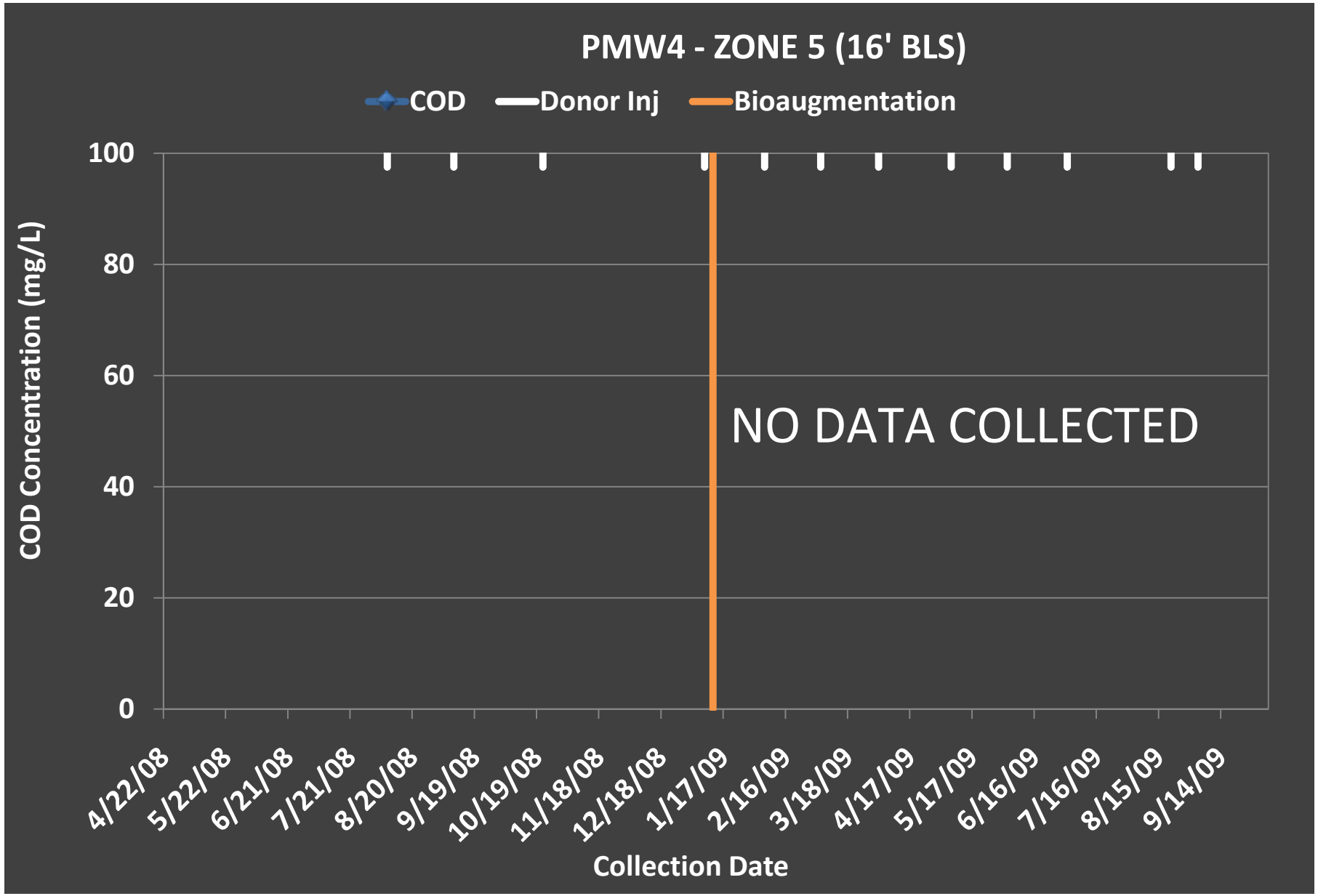

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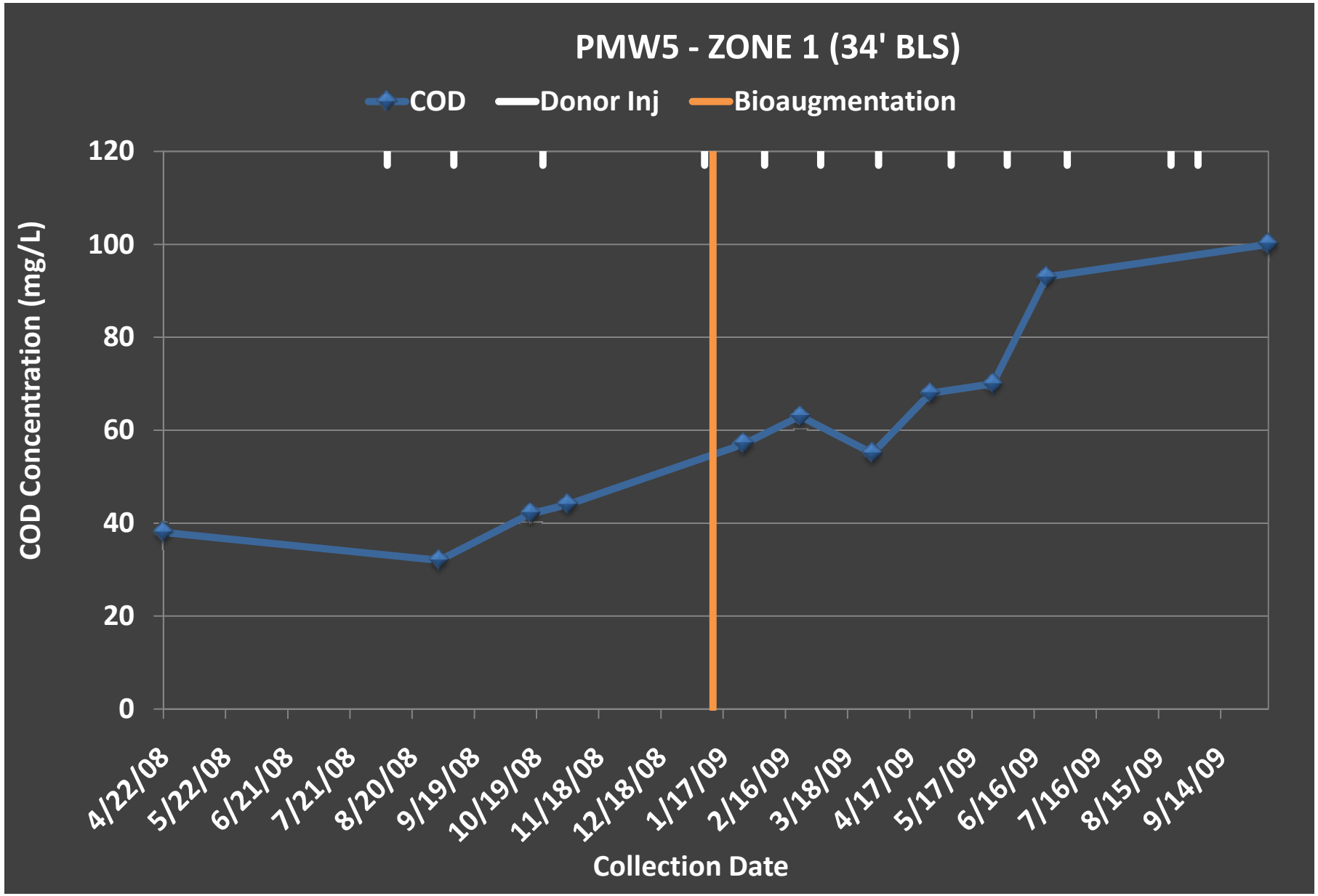

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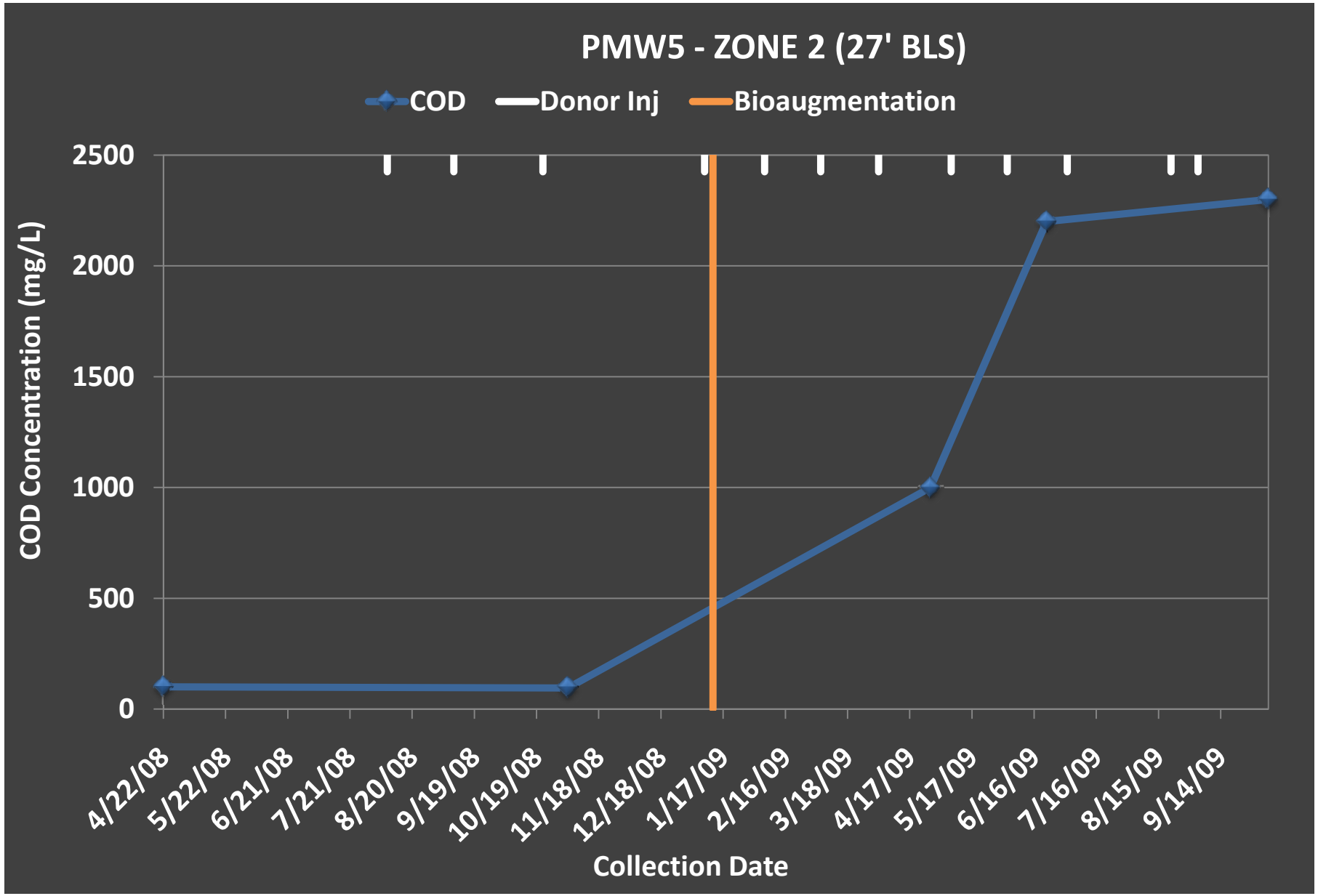

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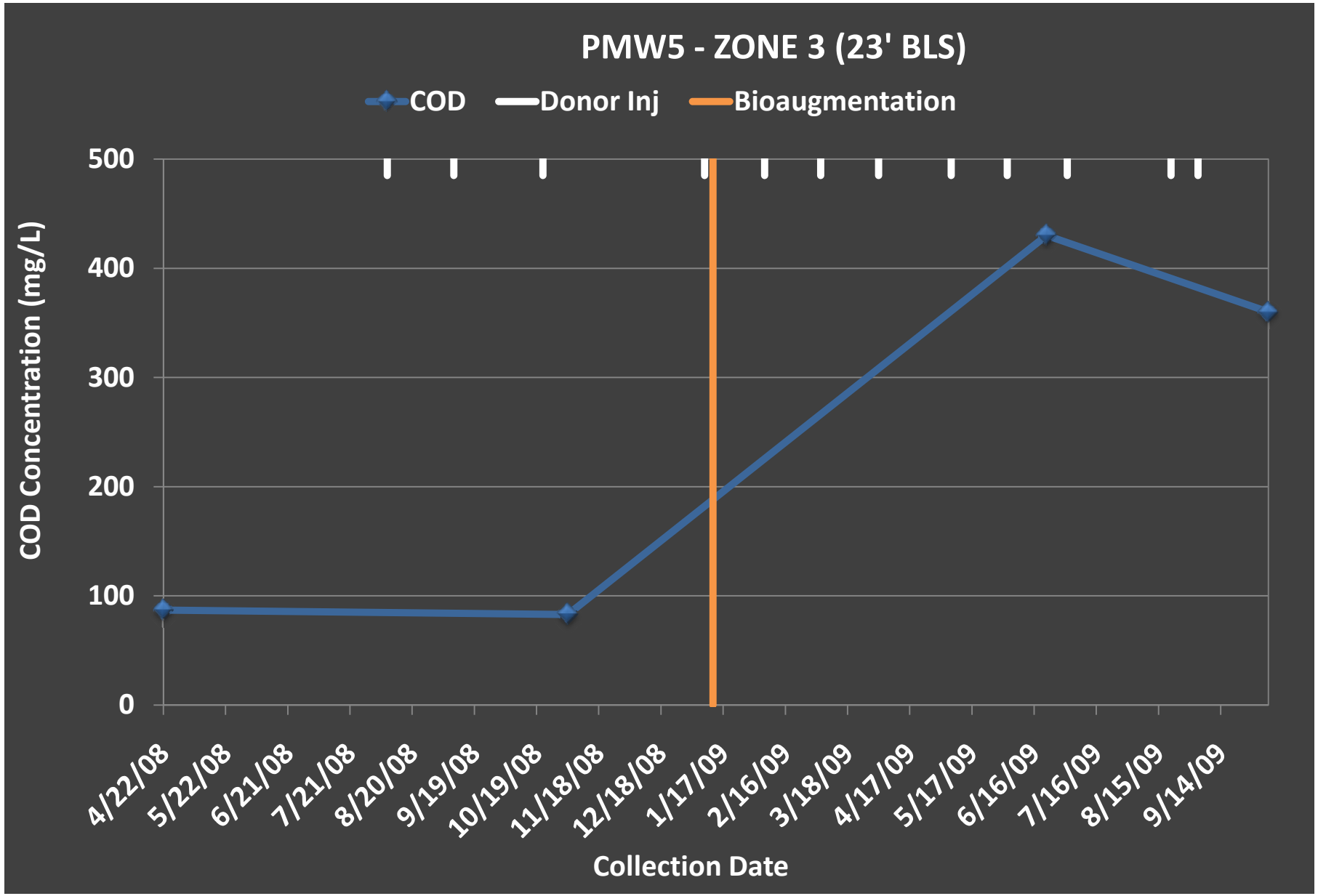

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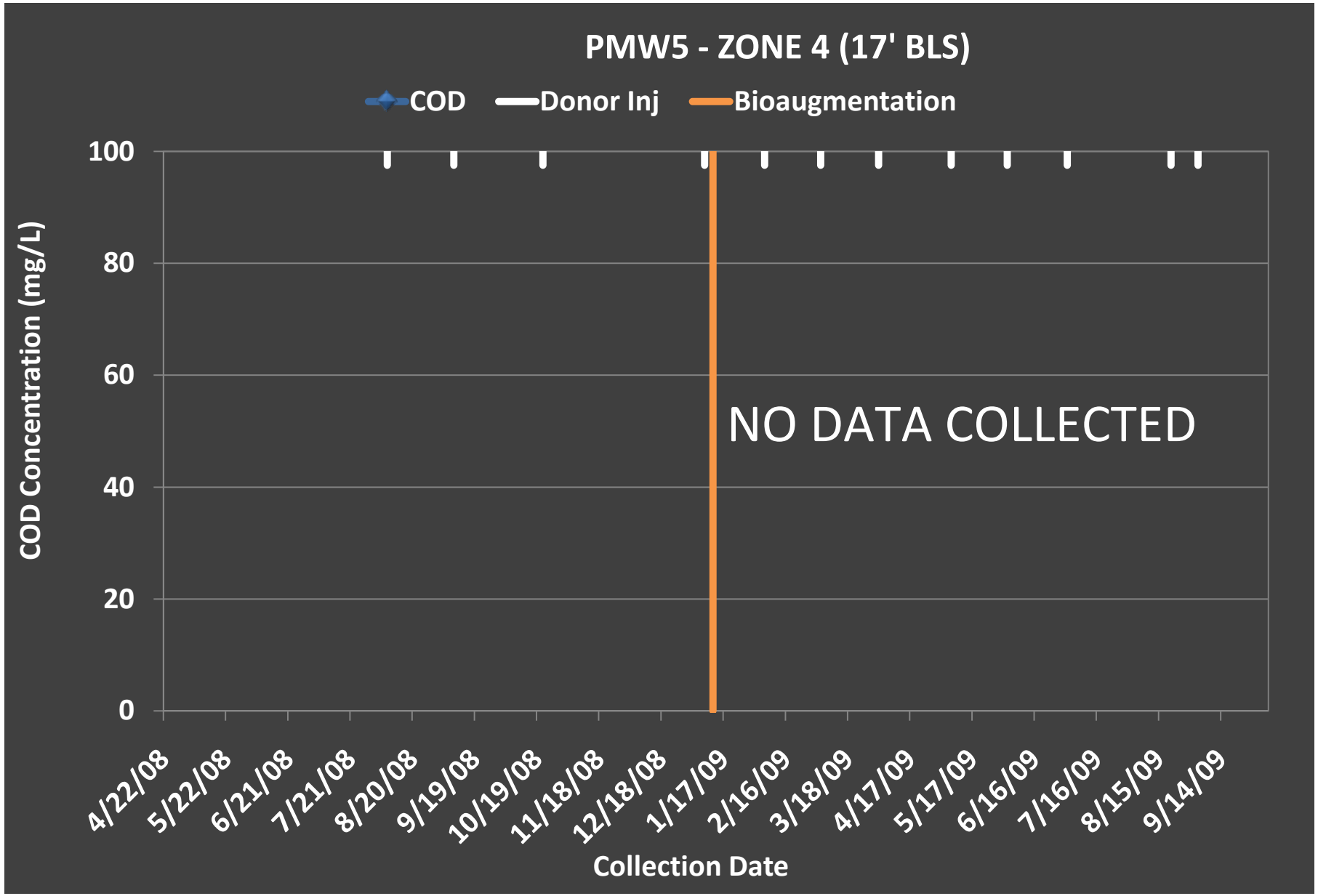

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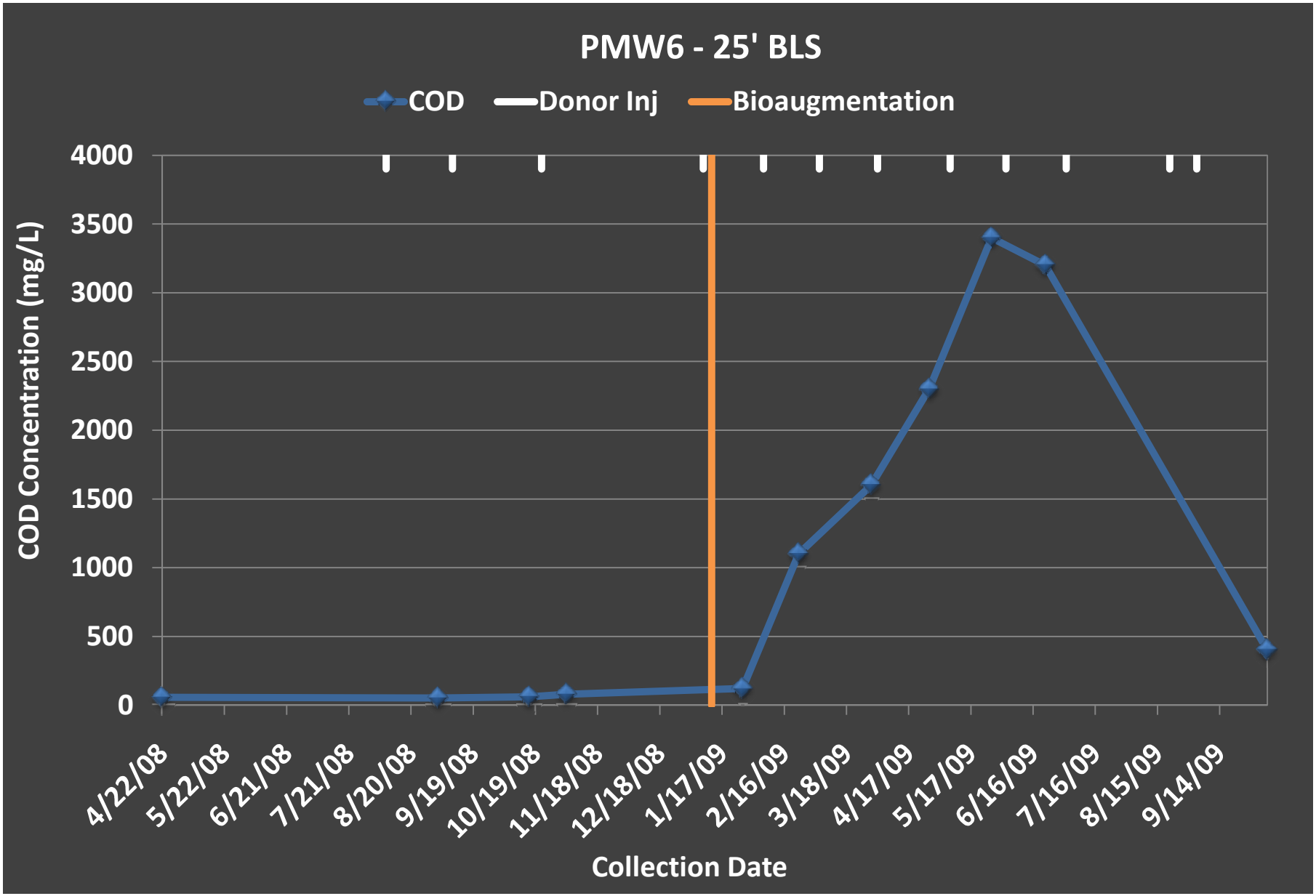

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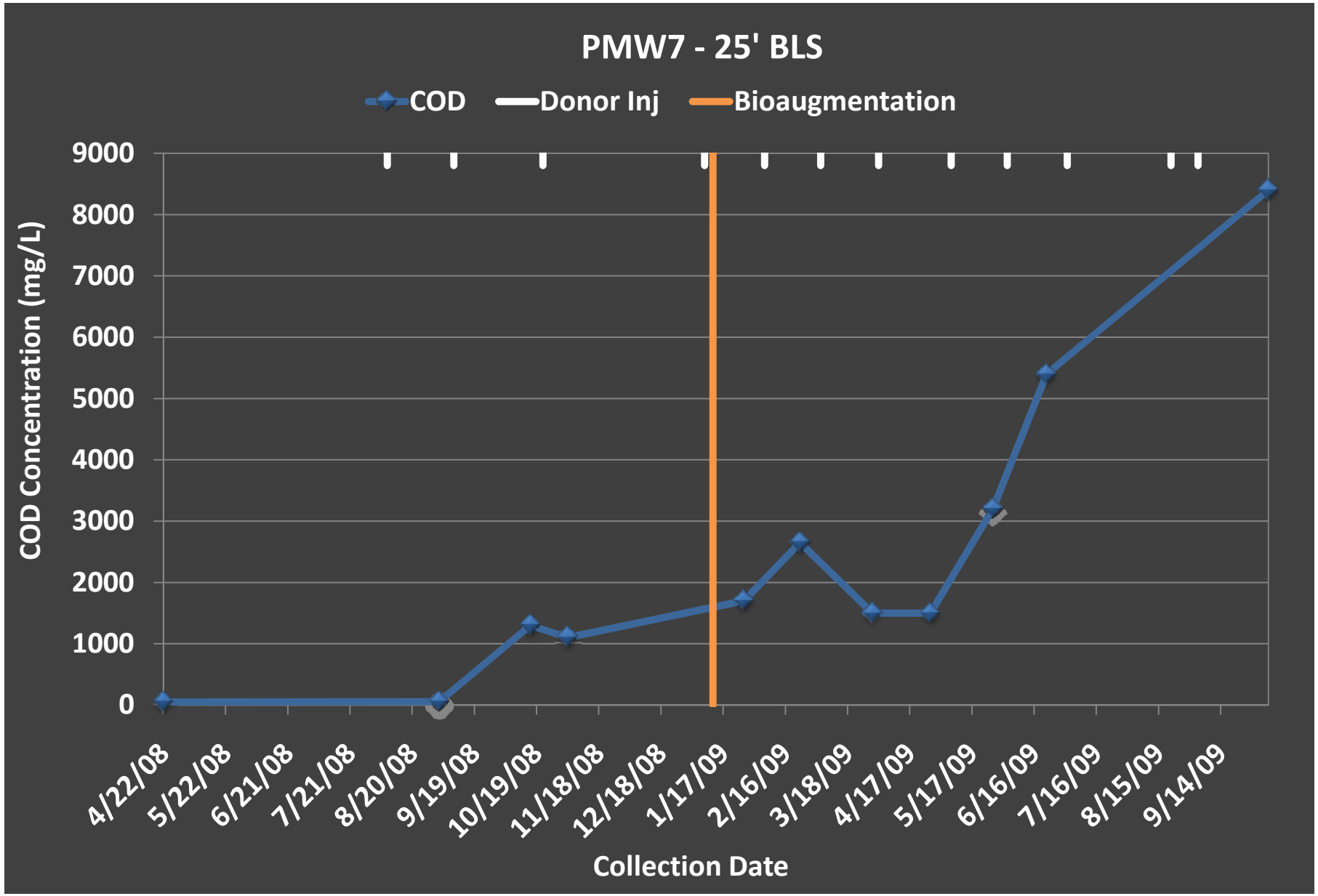

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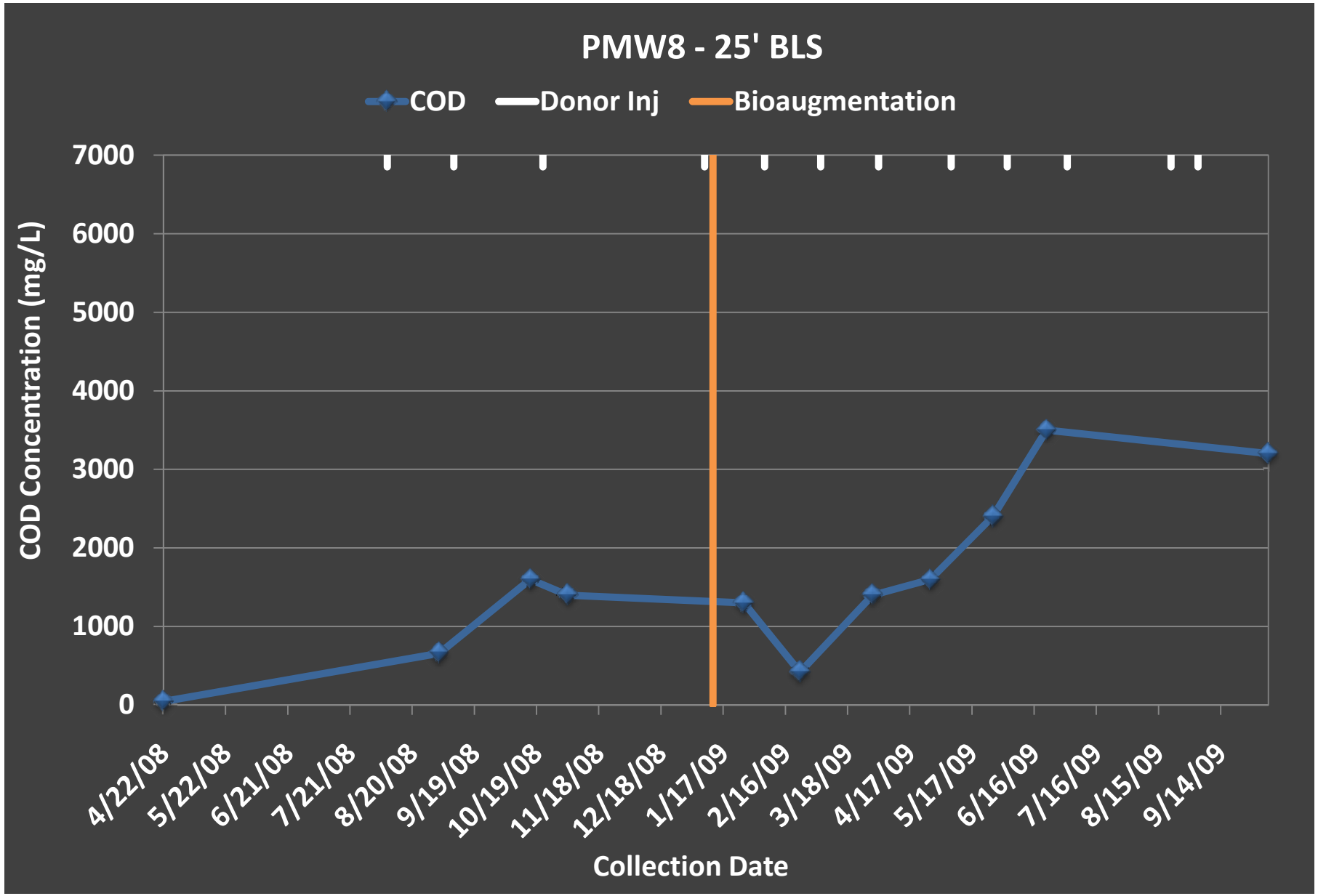

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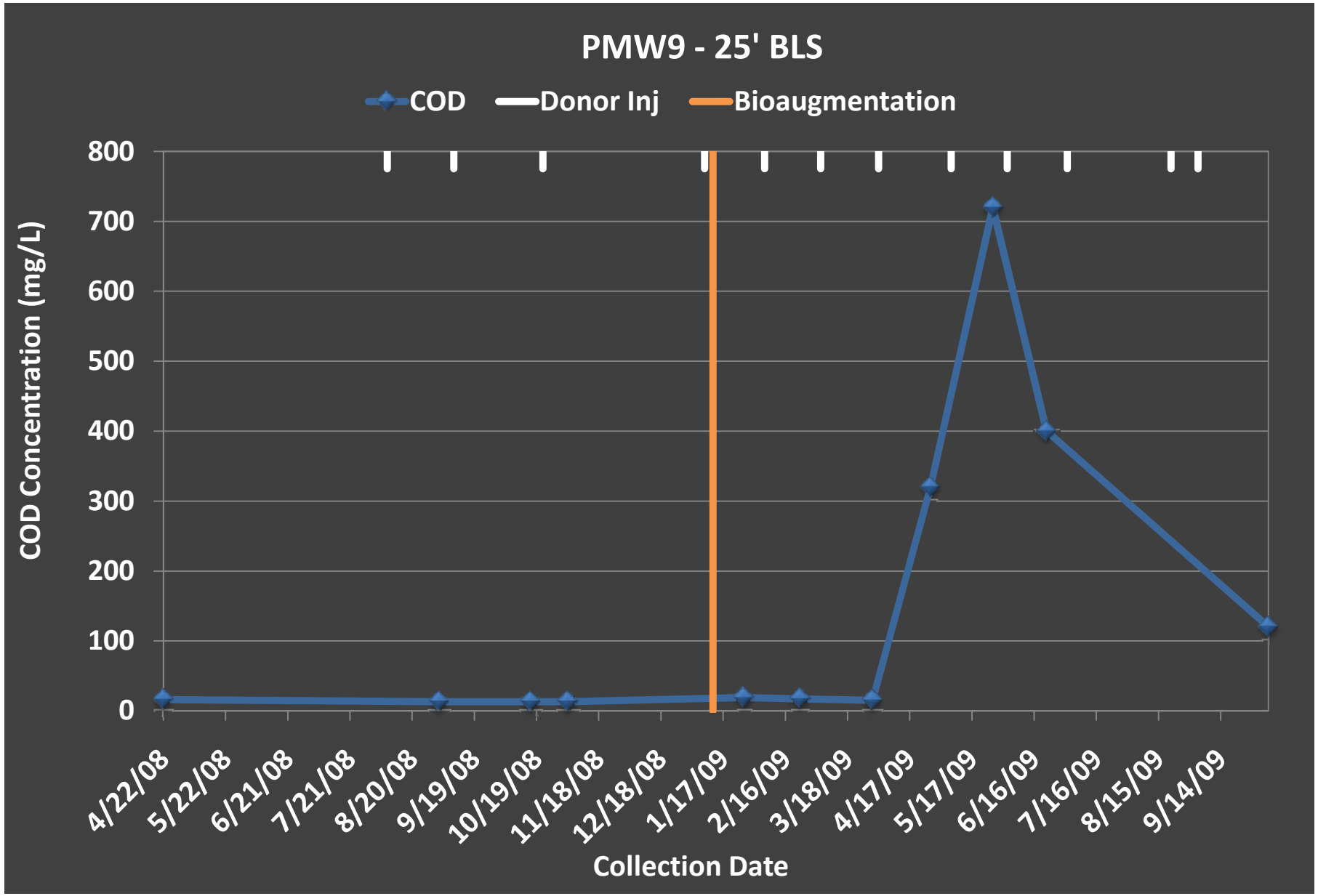

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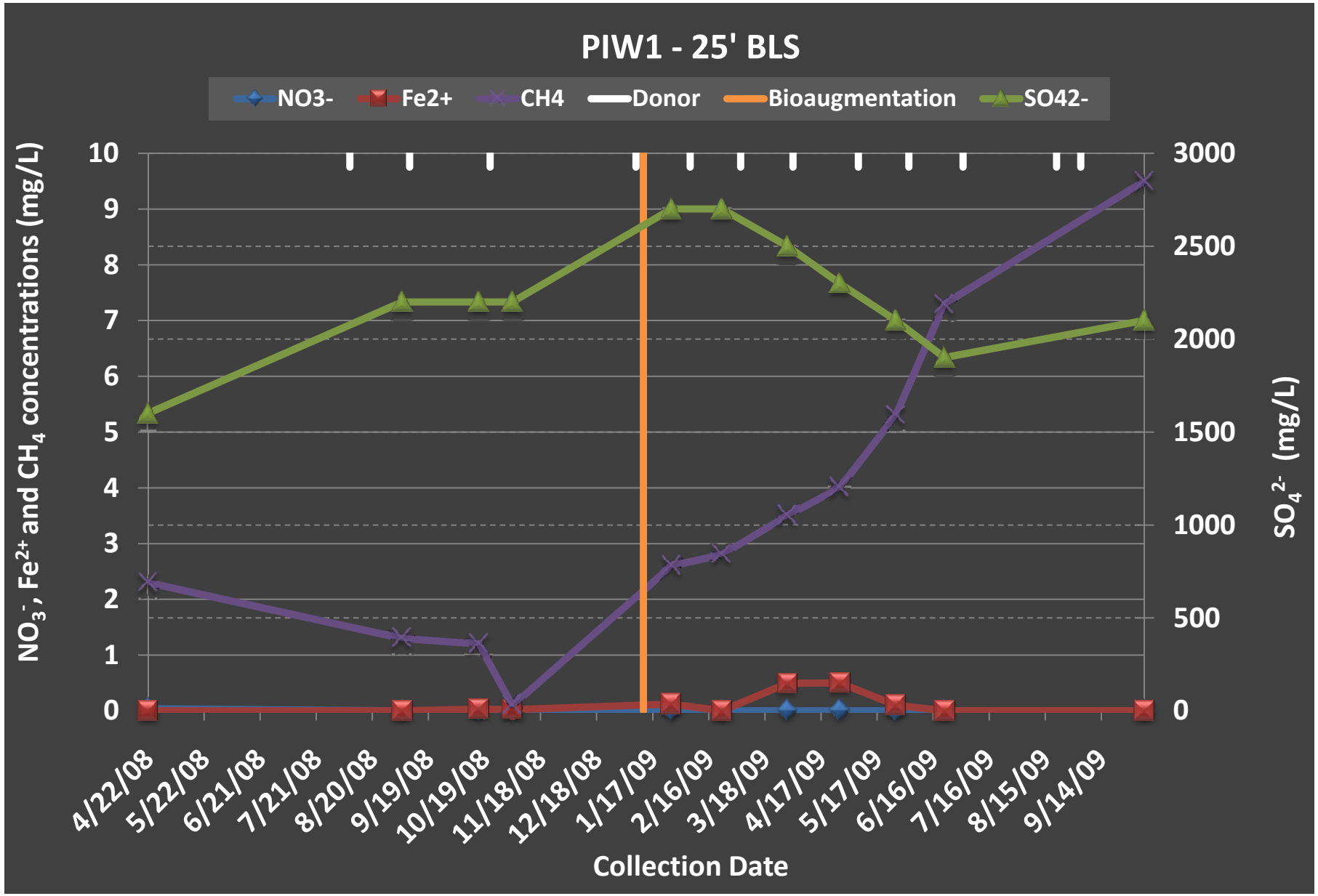
Electron Acceptors

Seal Beach
Groundwater Bioaugmentation



Seal Beach
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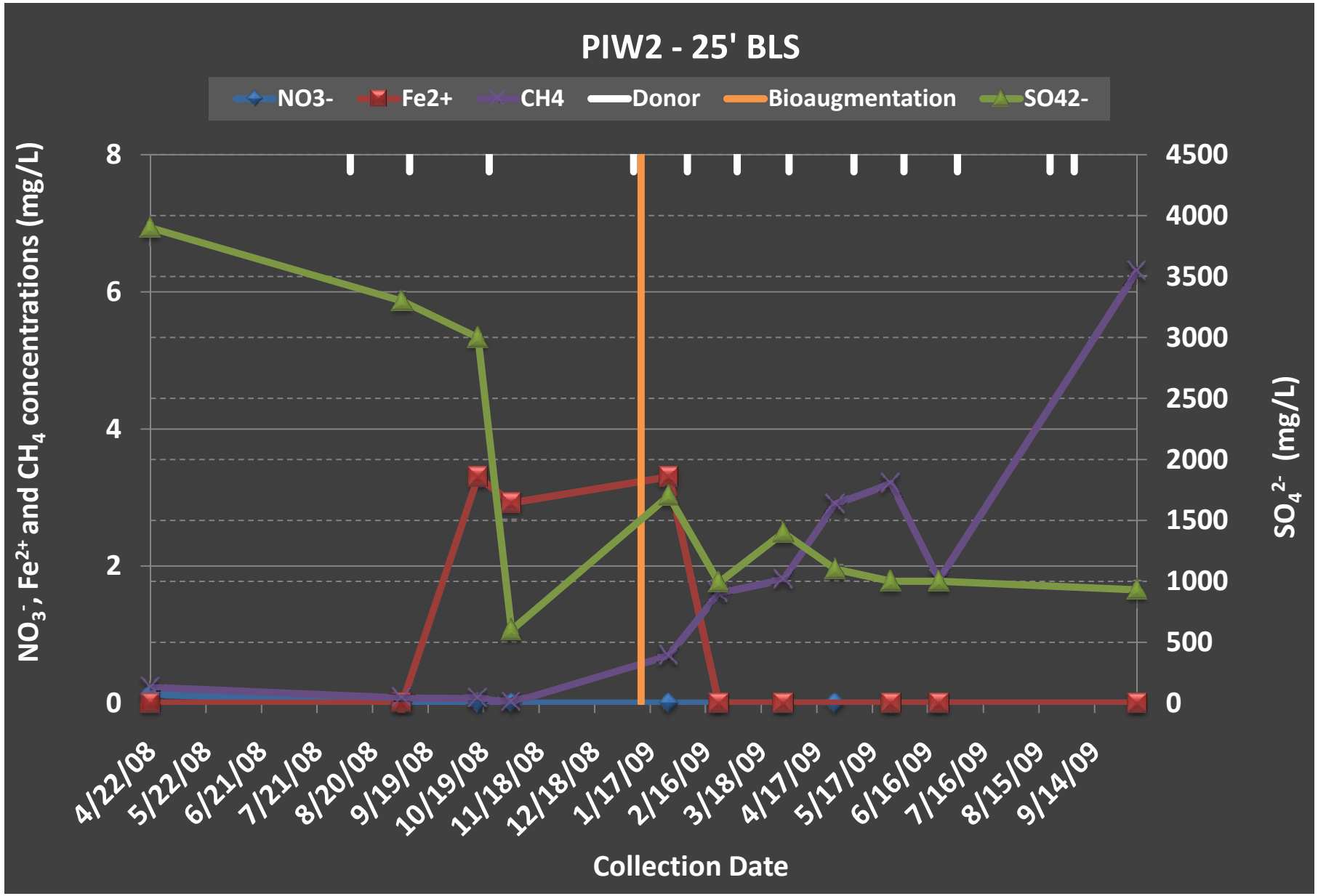

Seal Beach
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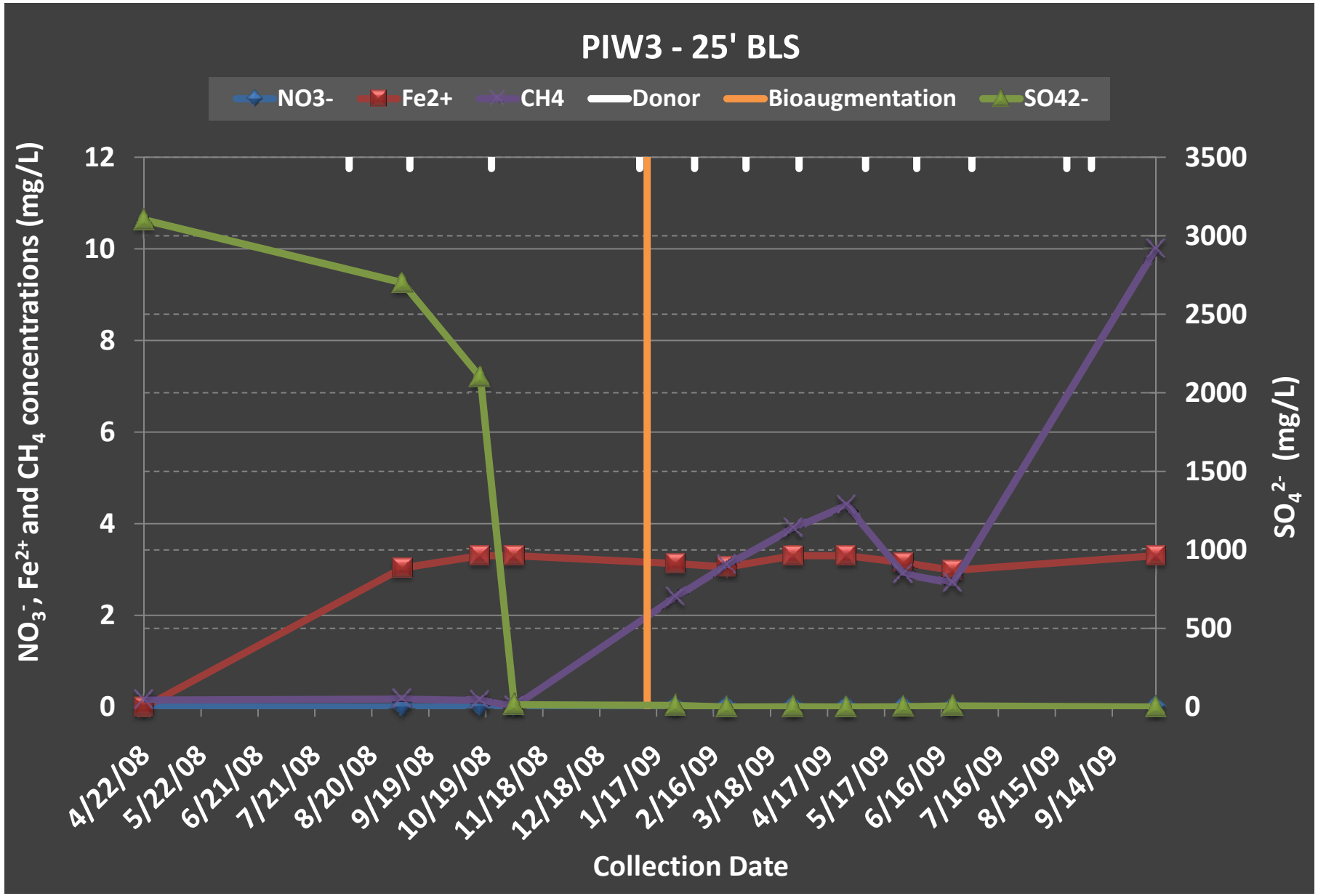

Seal Beach
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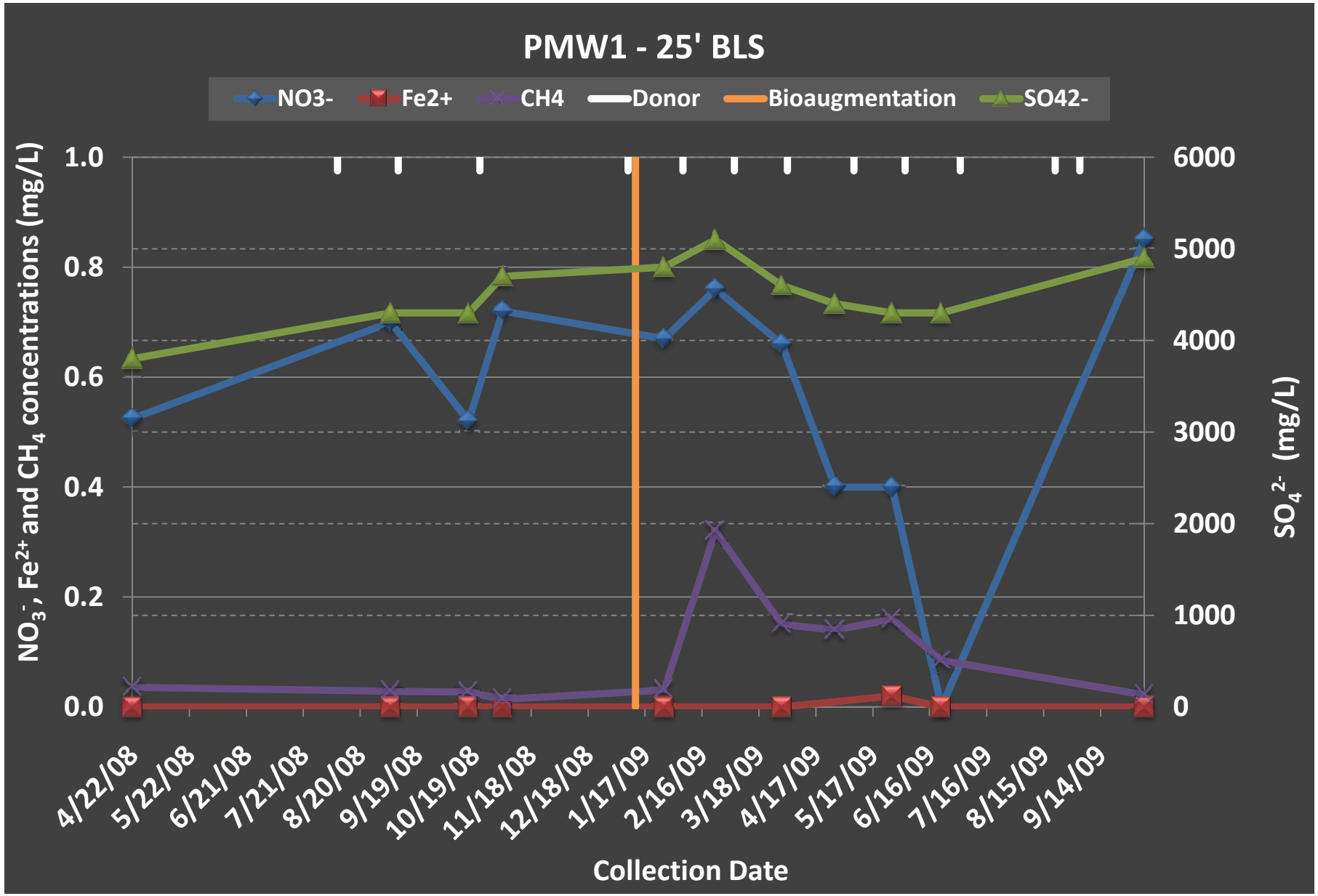

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Seal Beach
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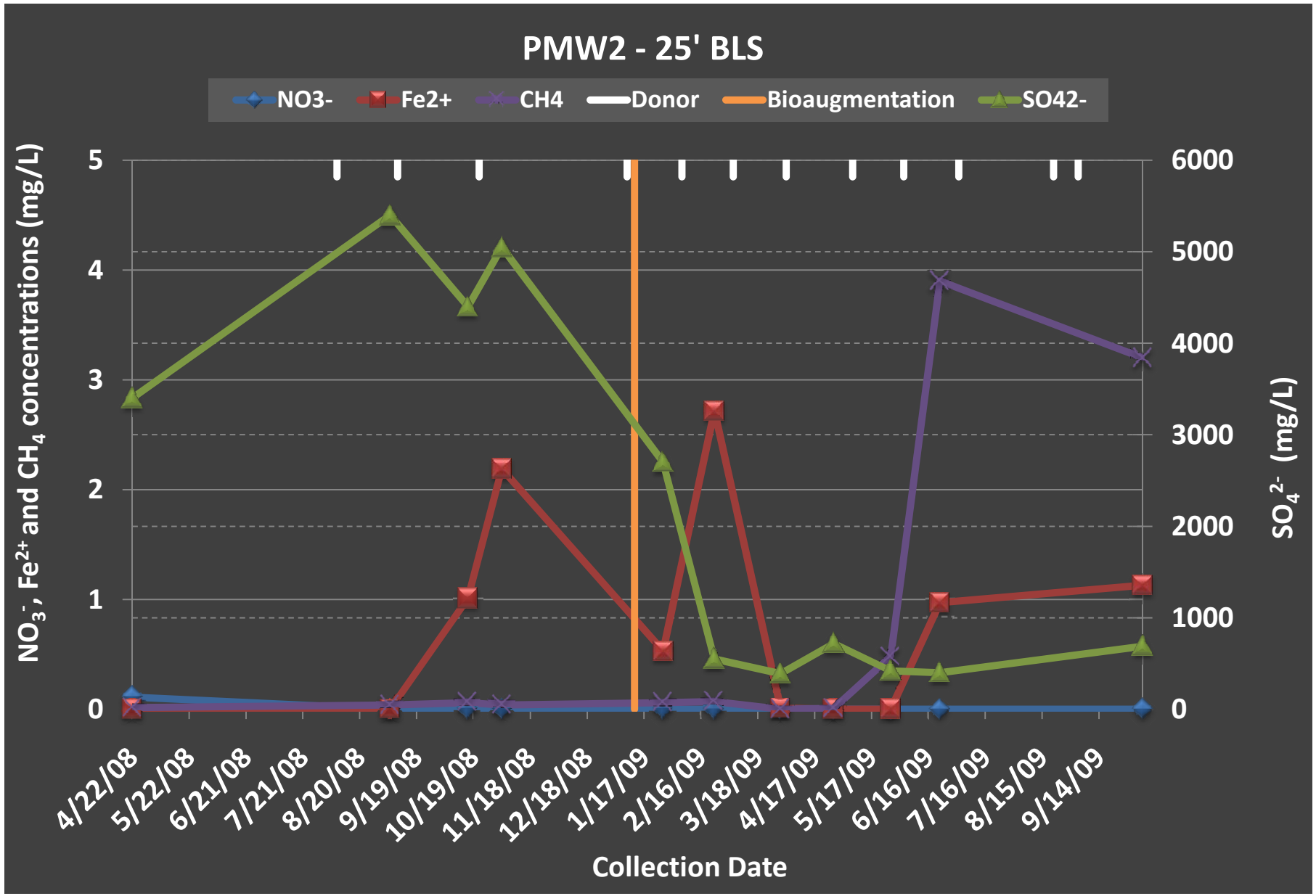

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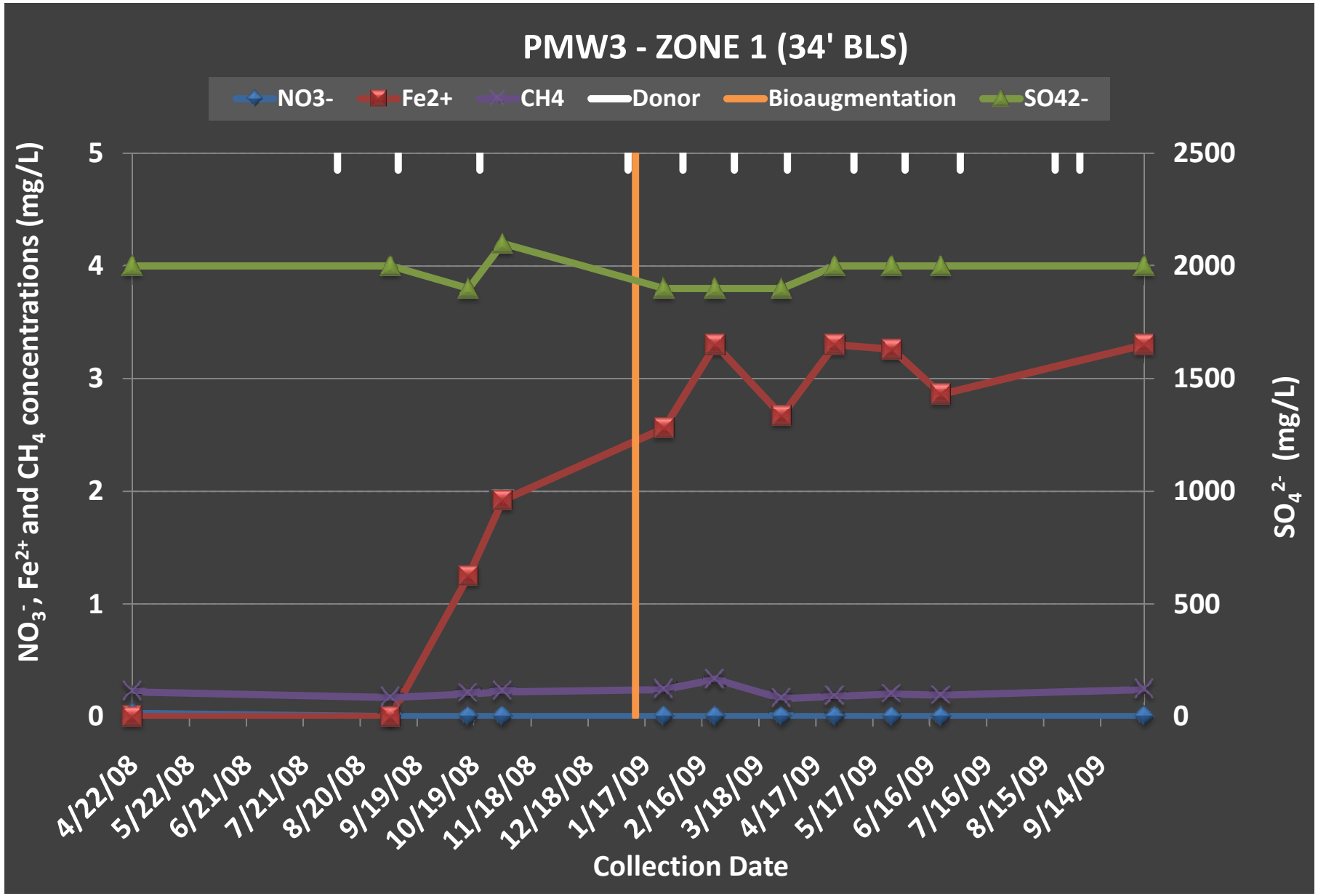

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Seal Beach
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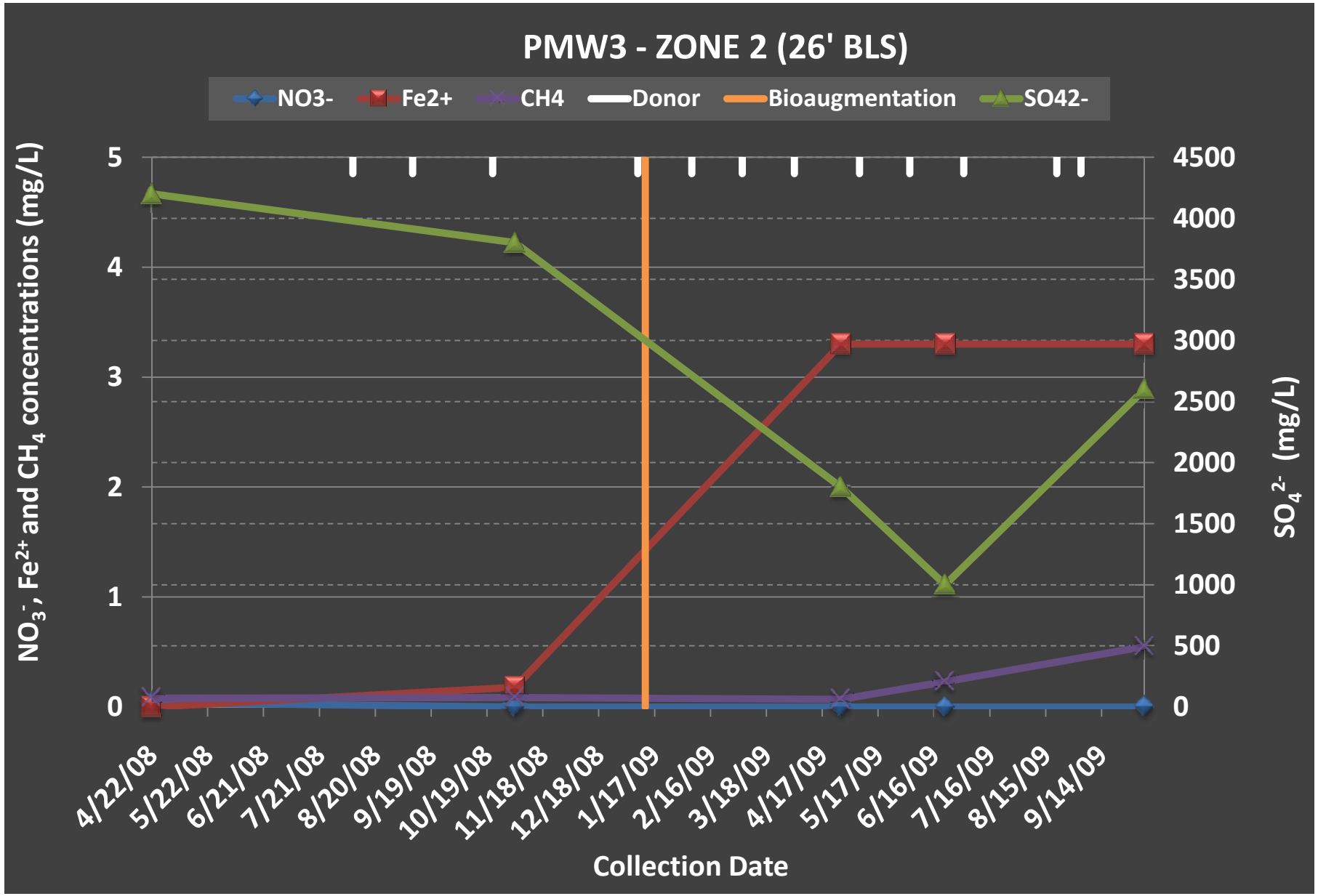
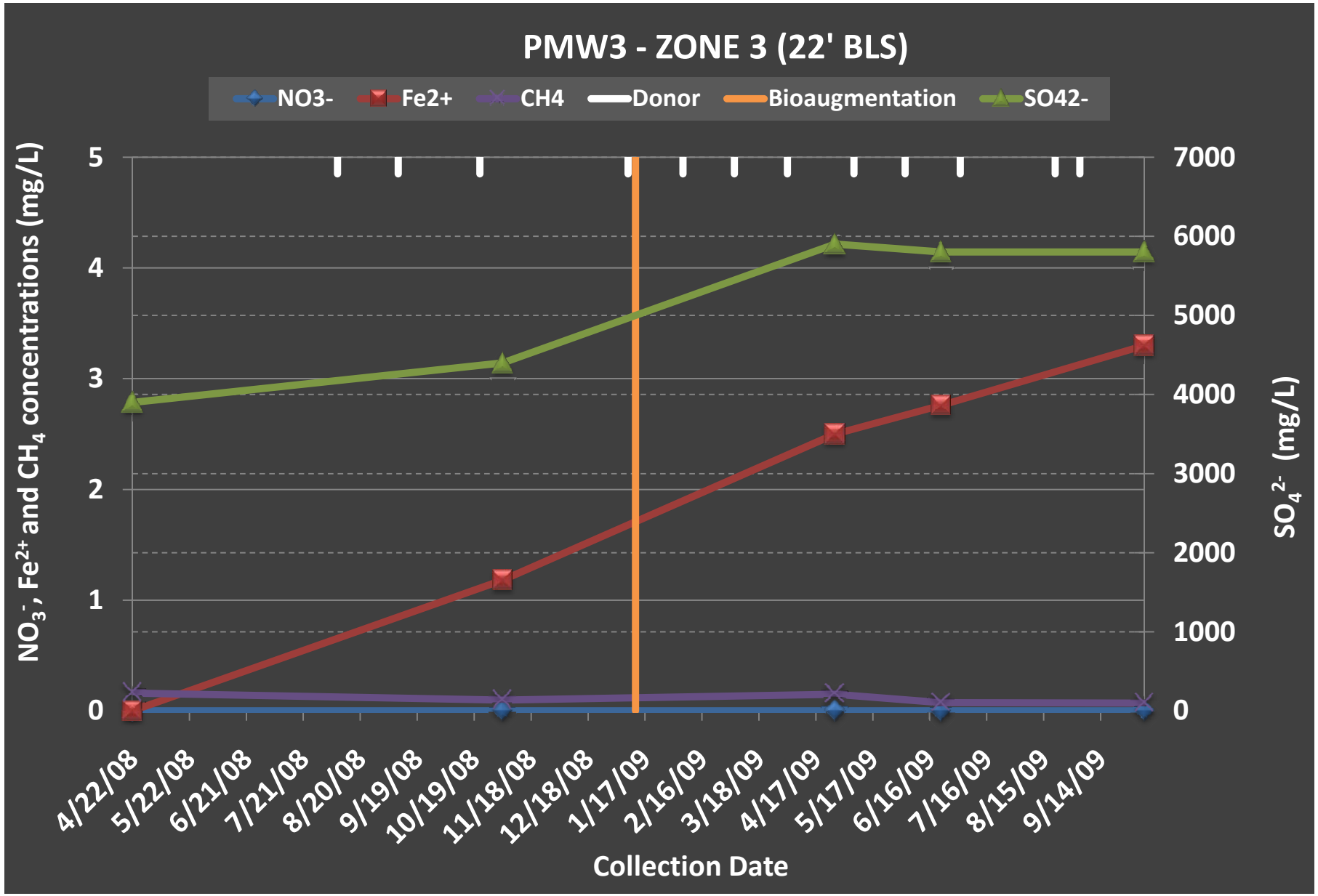


Seal Beach
Groundwater Bioaugmentation



Seal Beach
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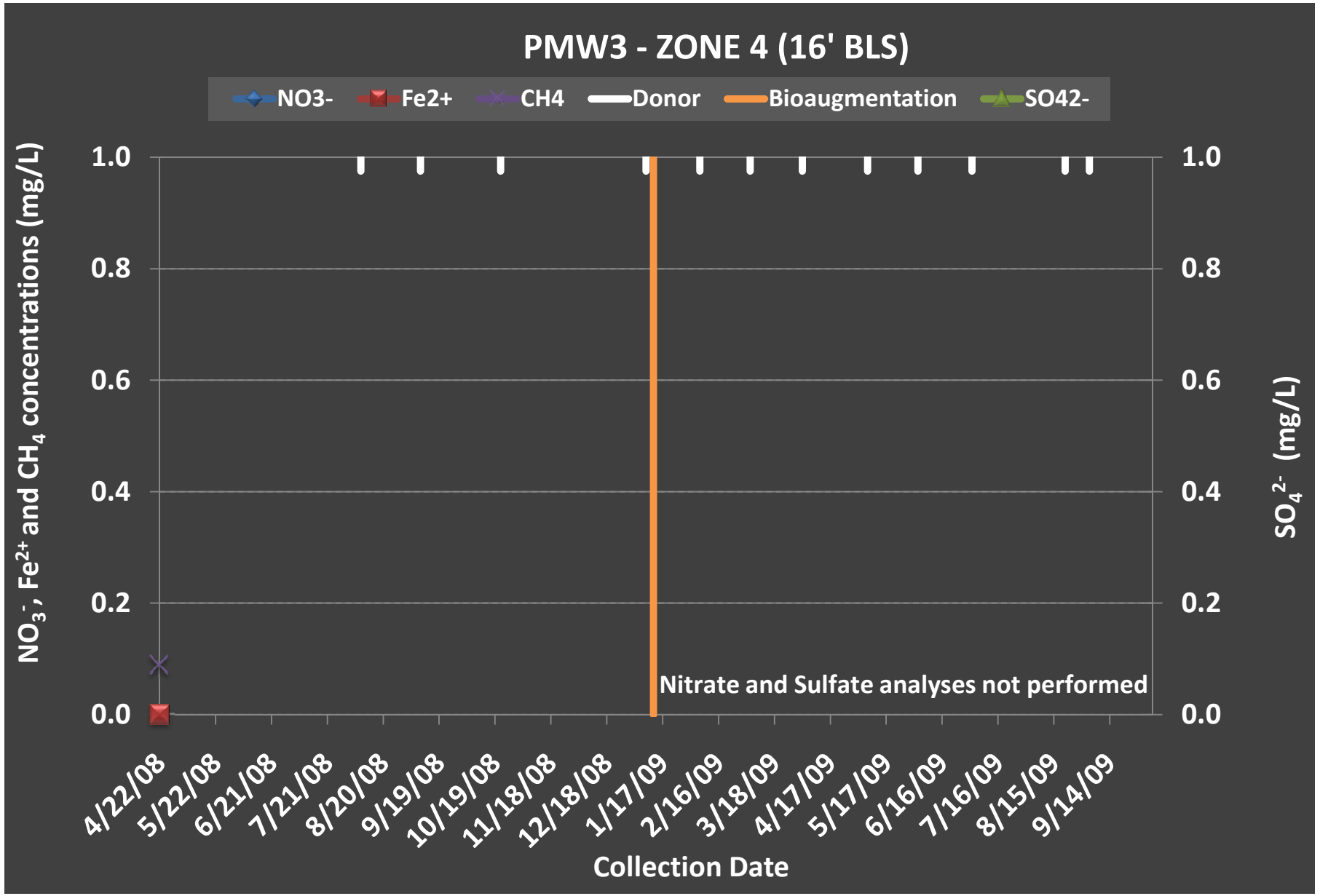
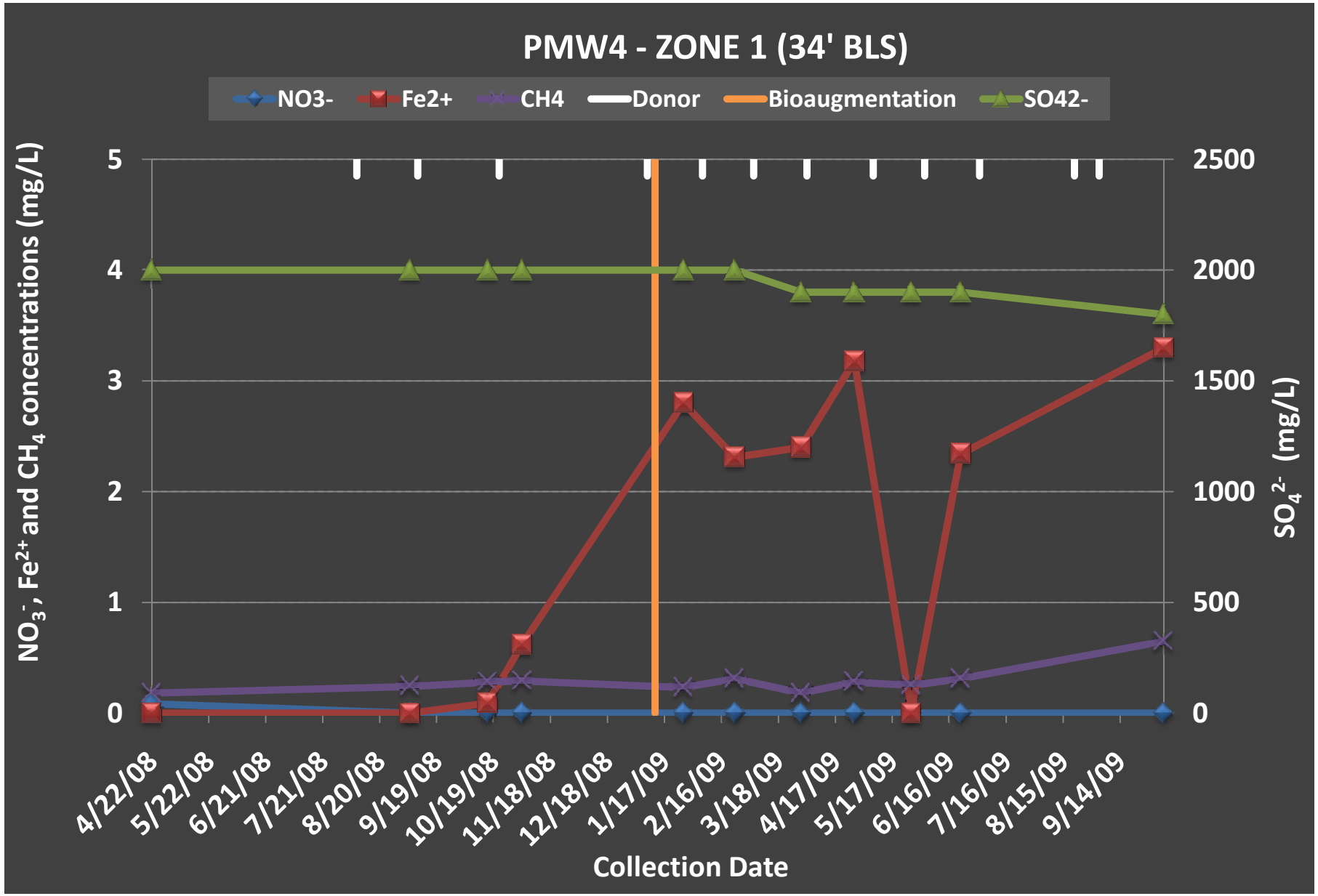


Seal Beach
Groundwater Bioaugmentation



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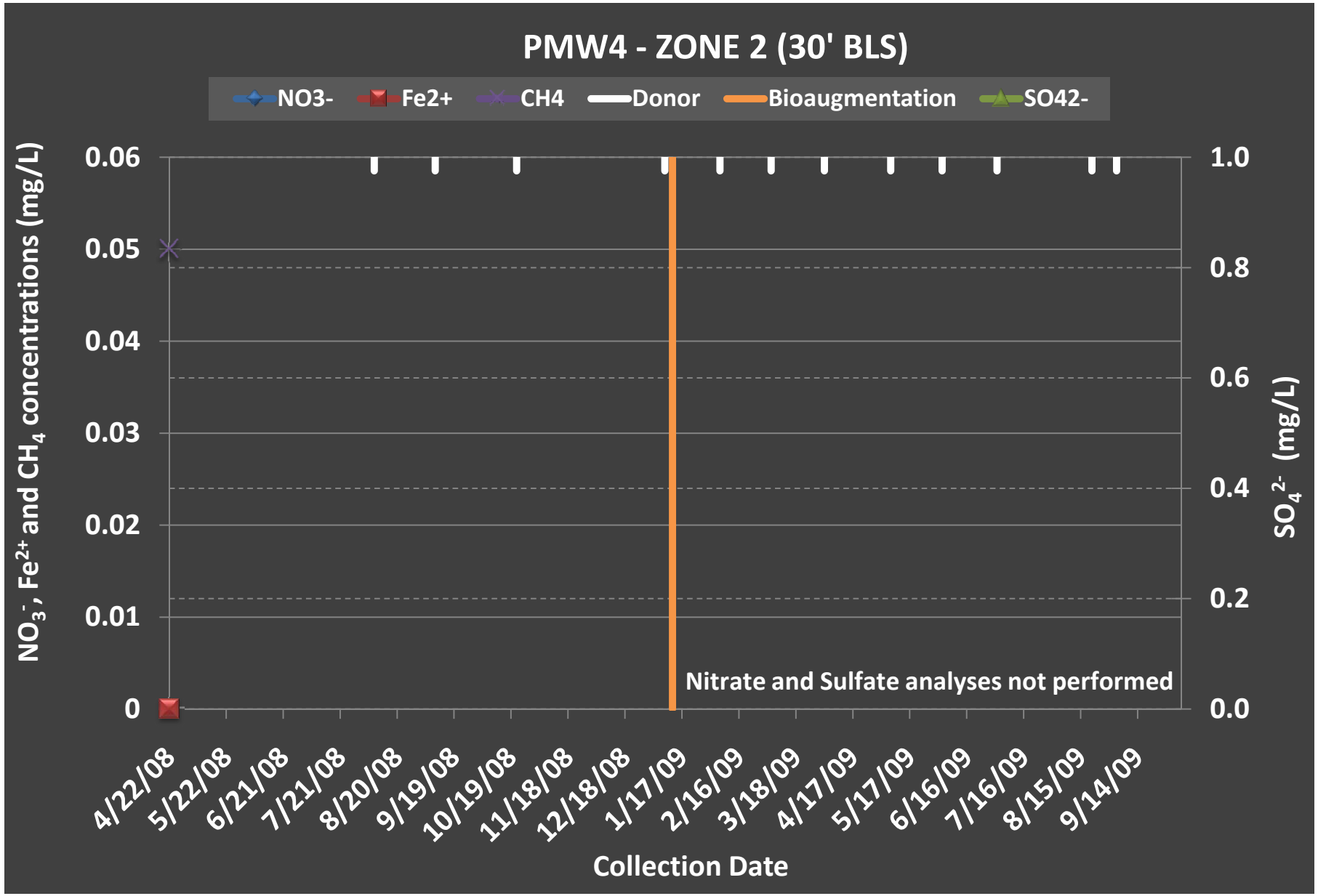

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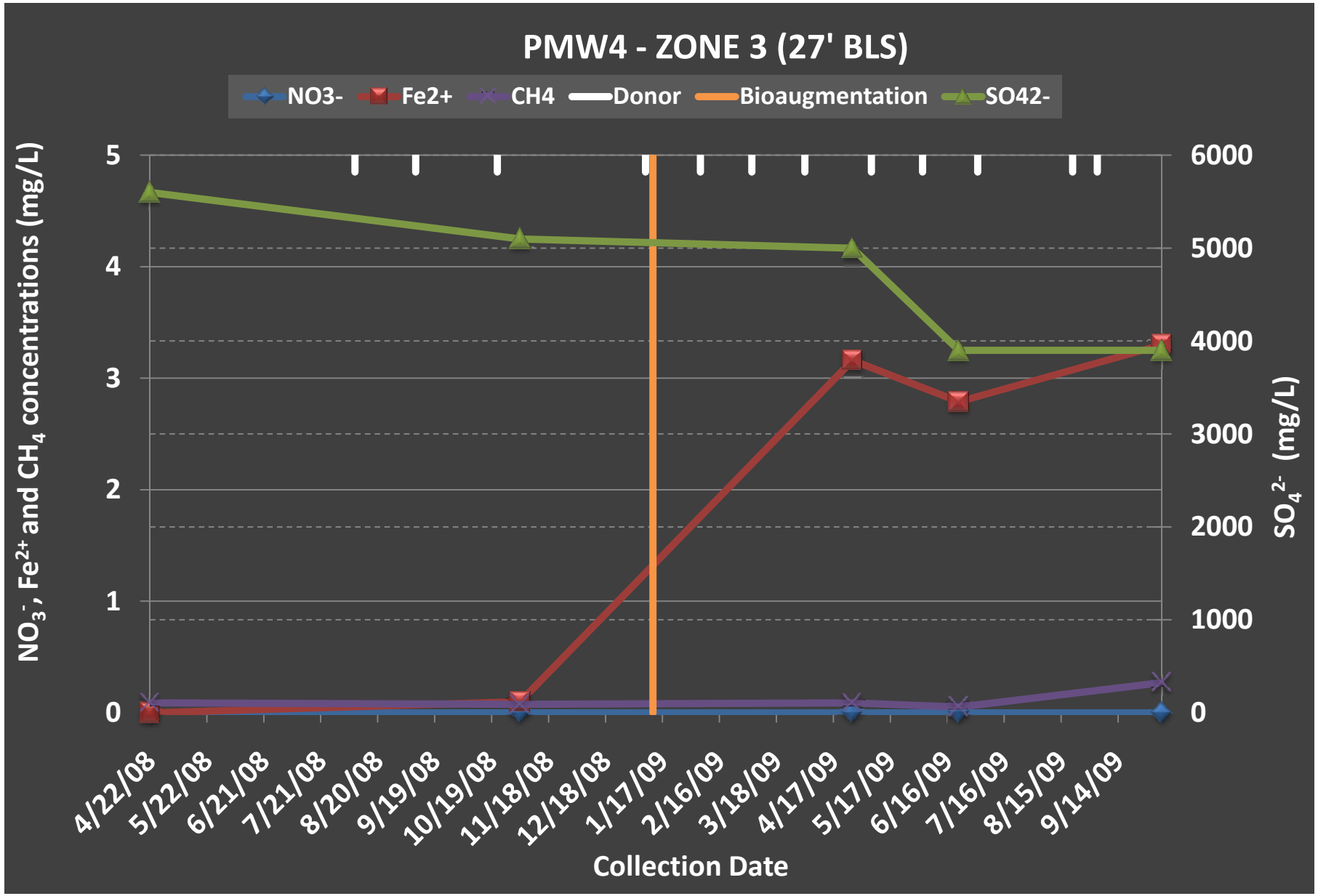

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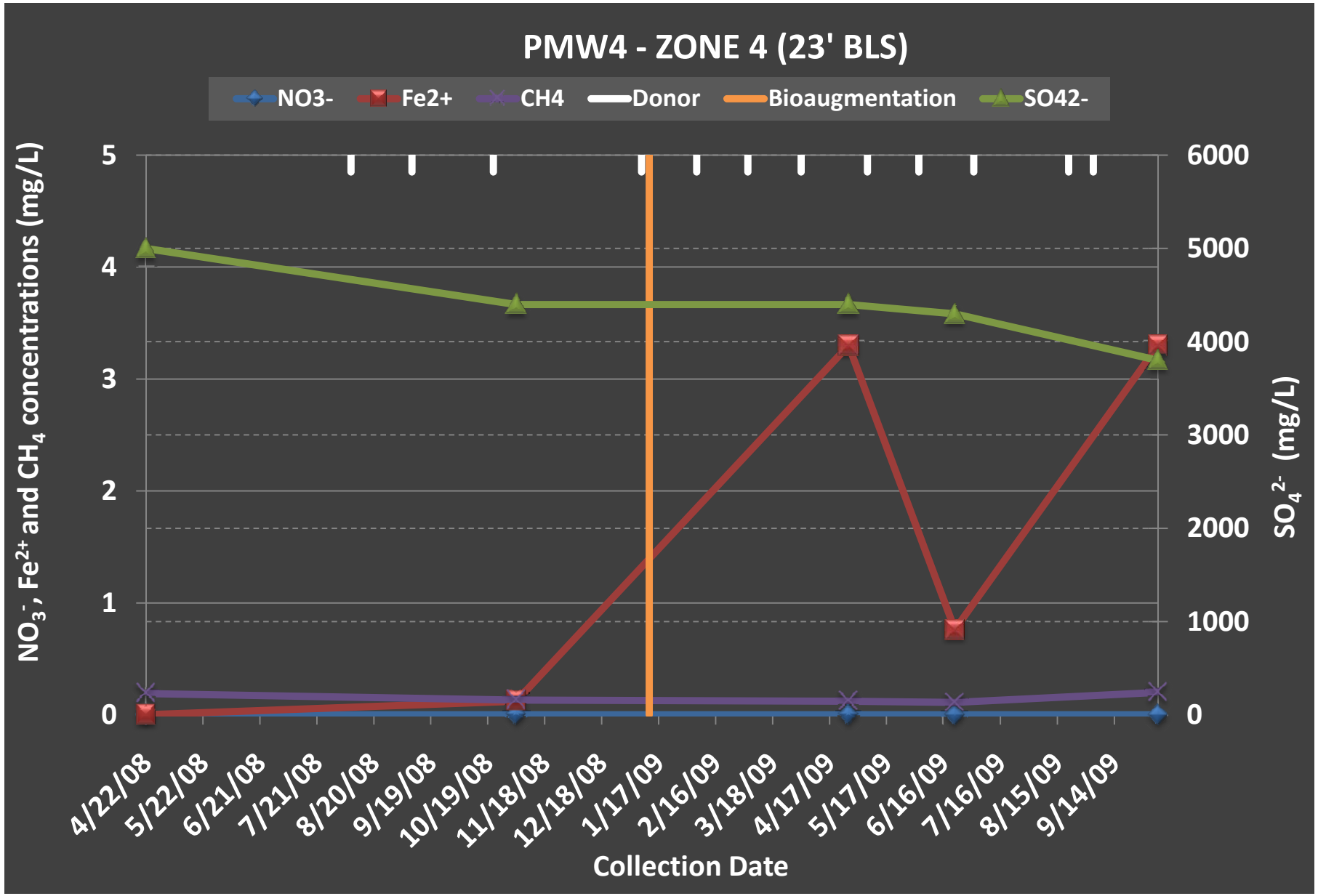

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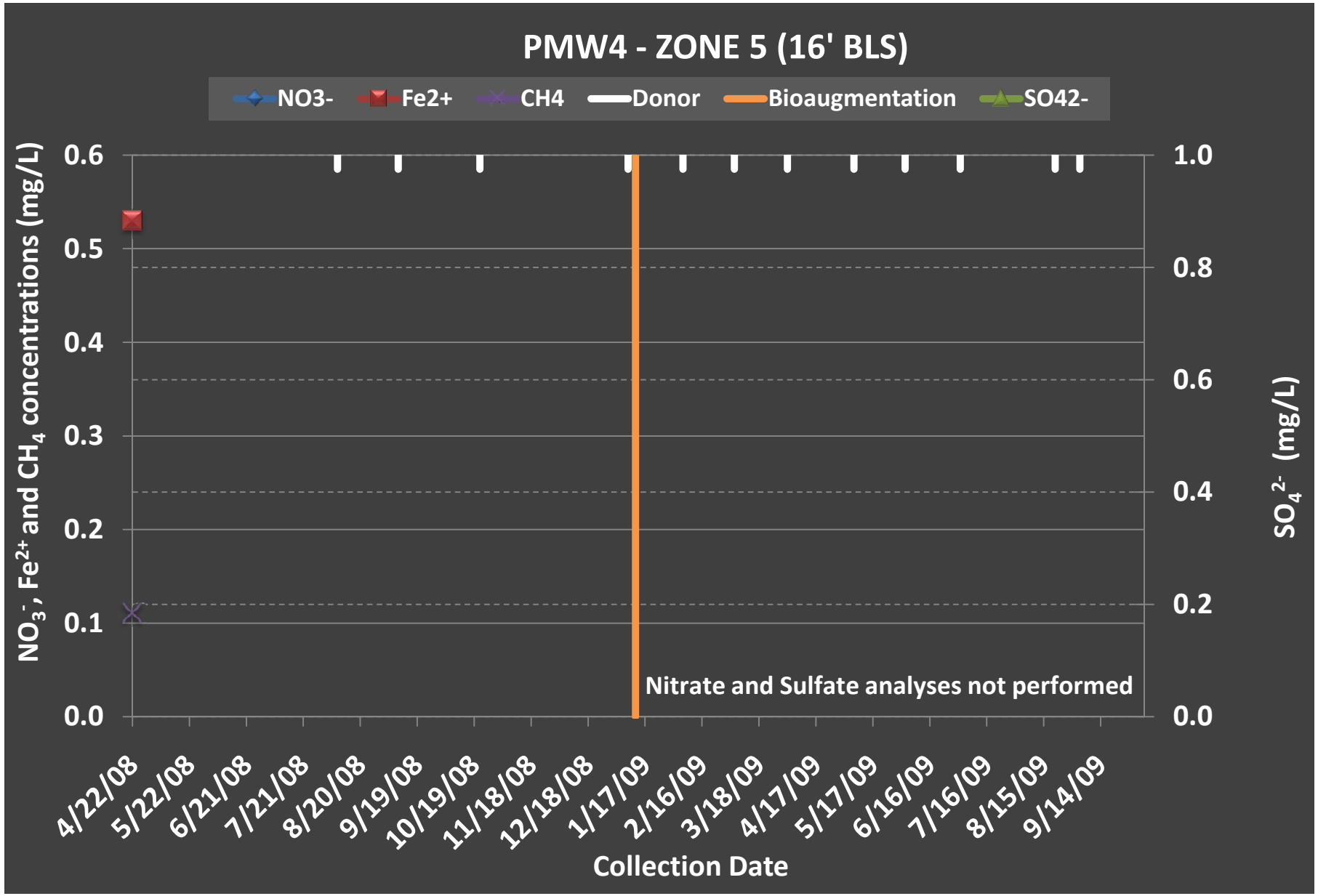

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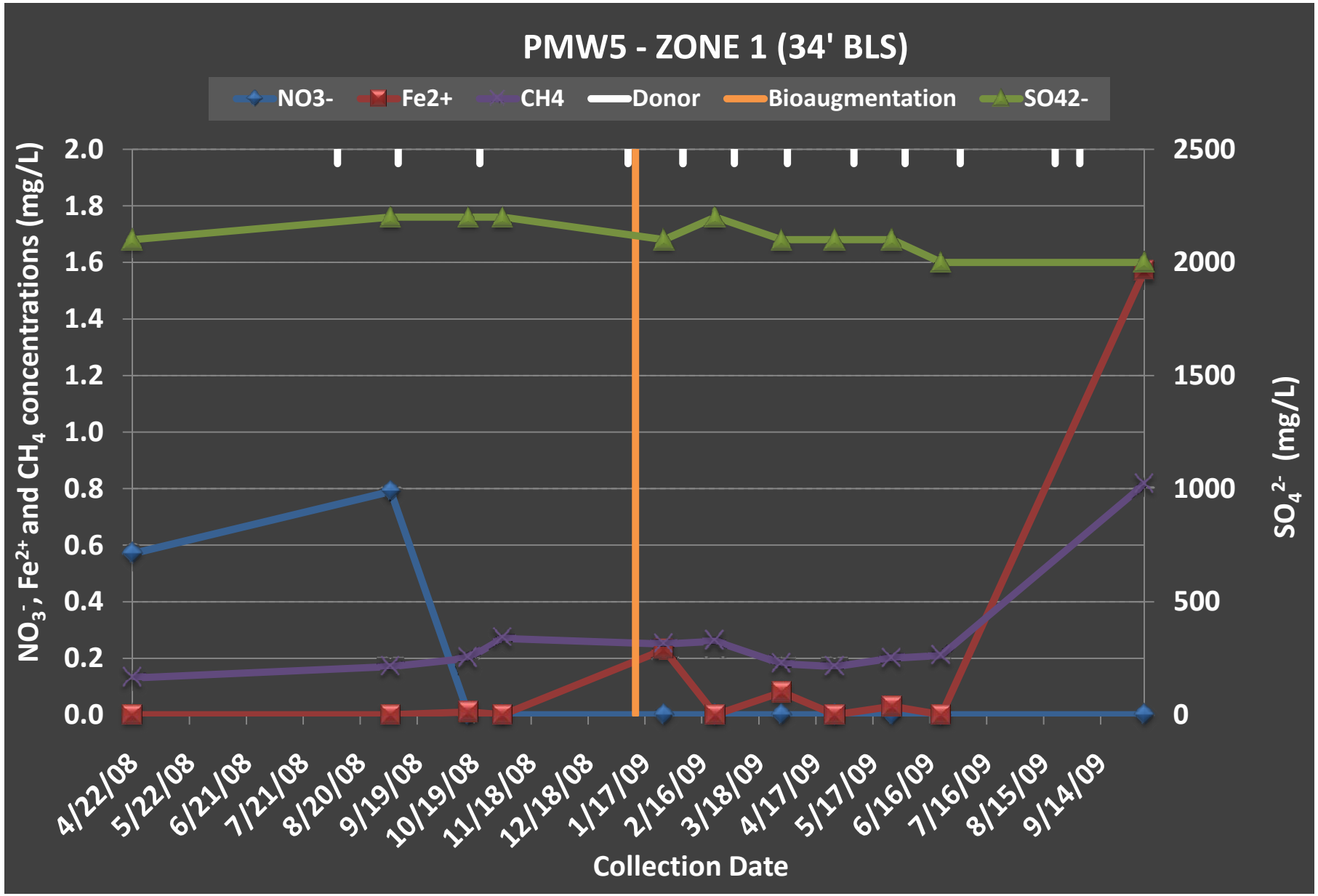

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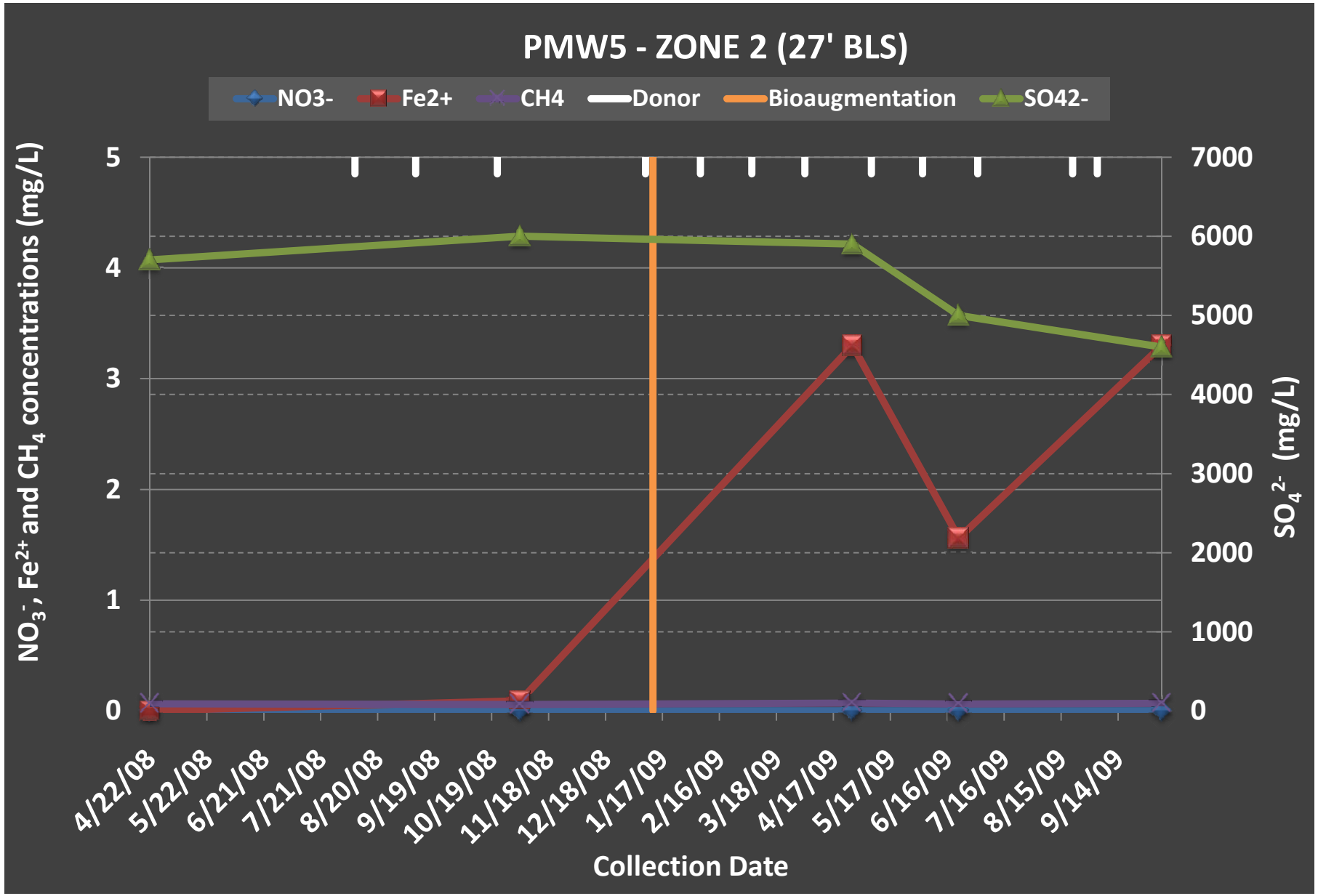

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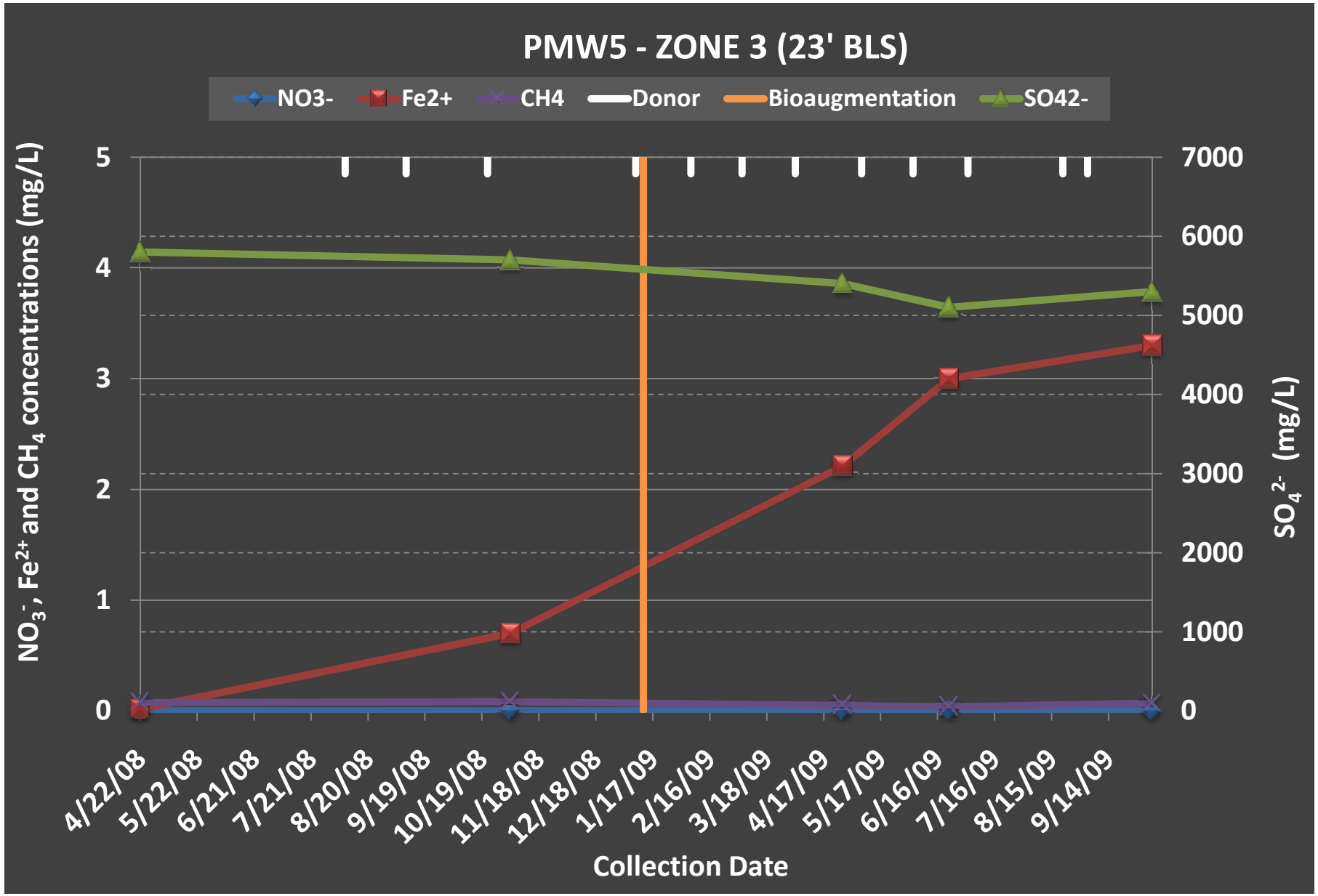

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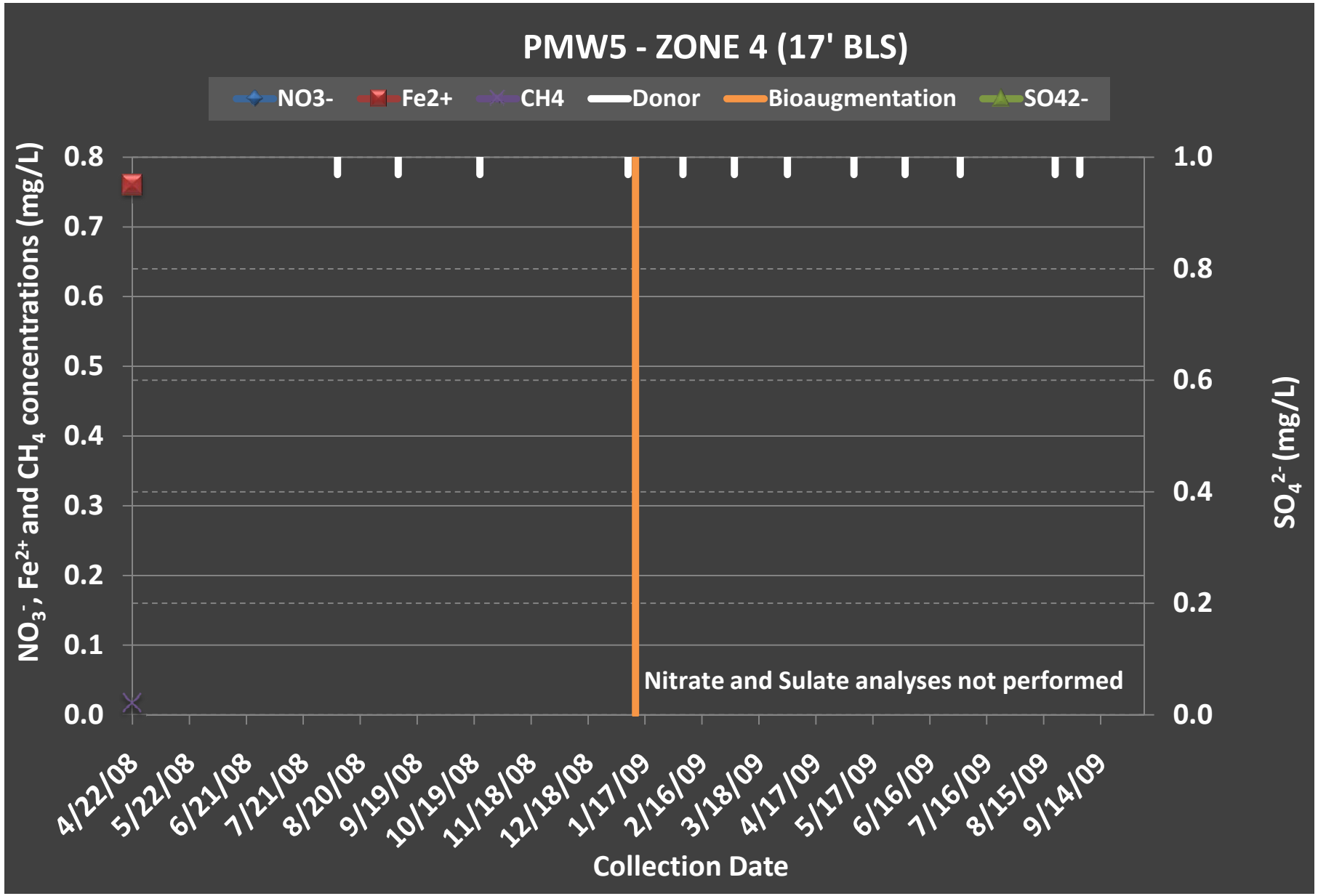

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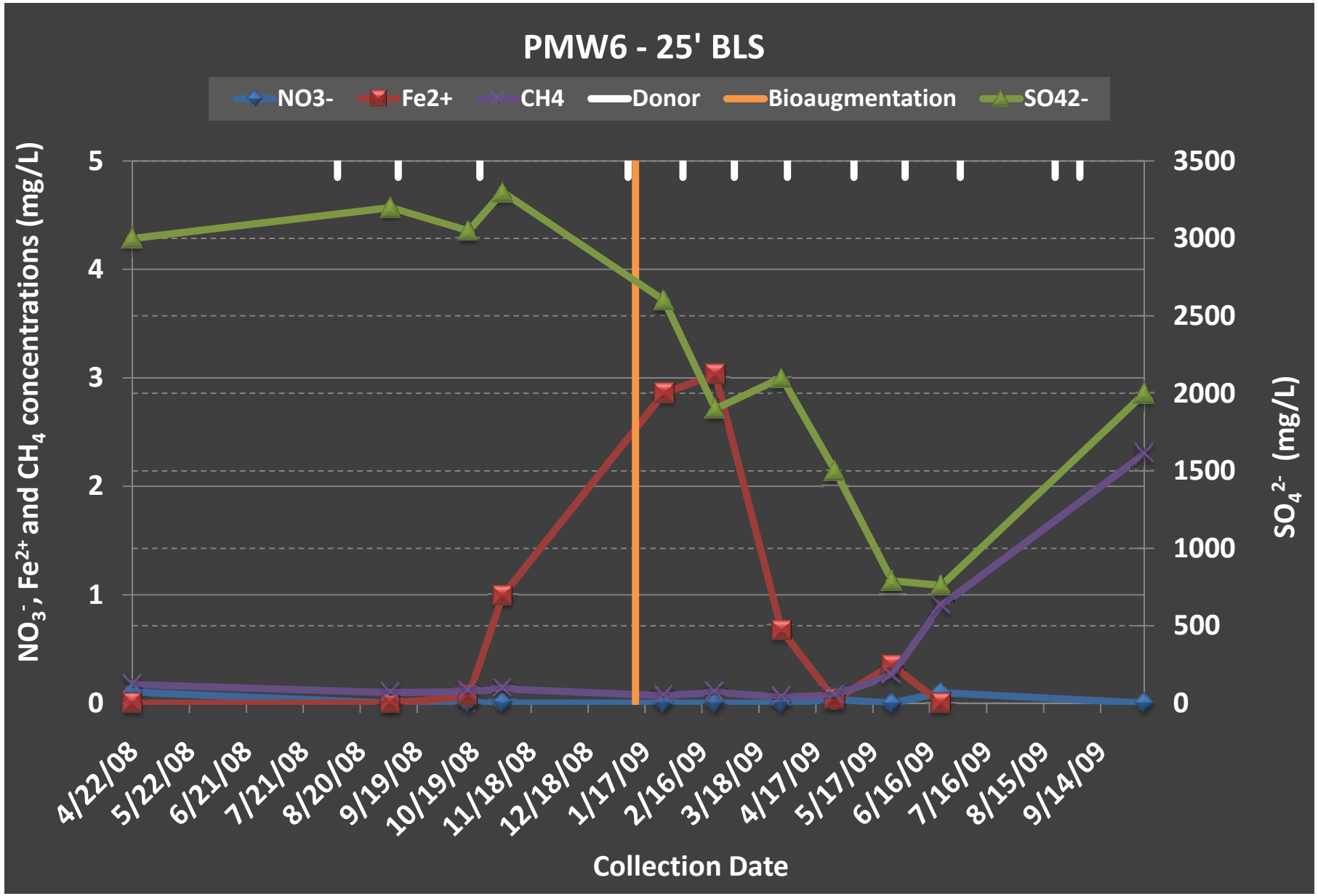
Groundwater Bioaugmentation



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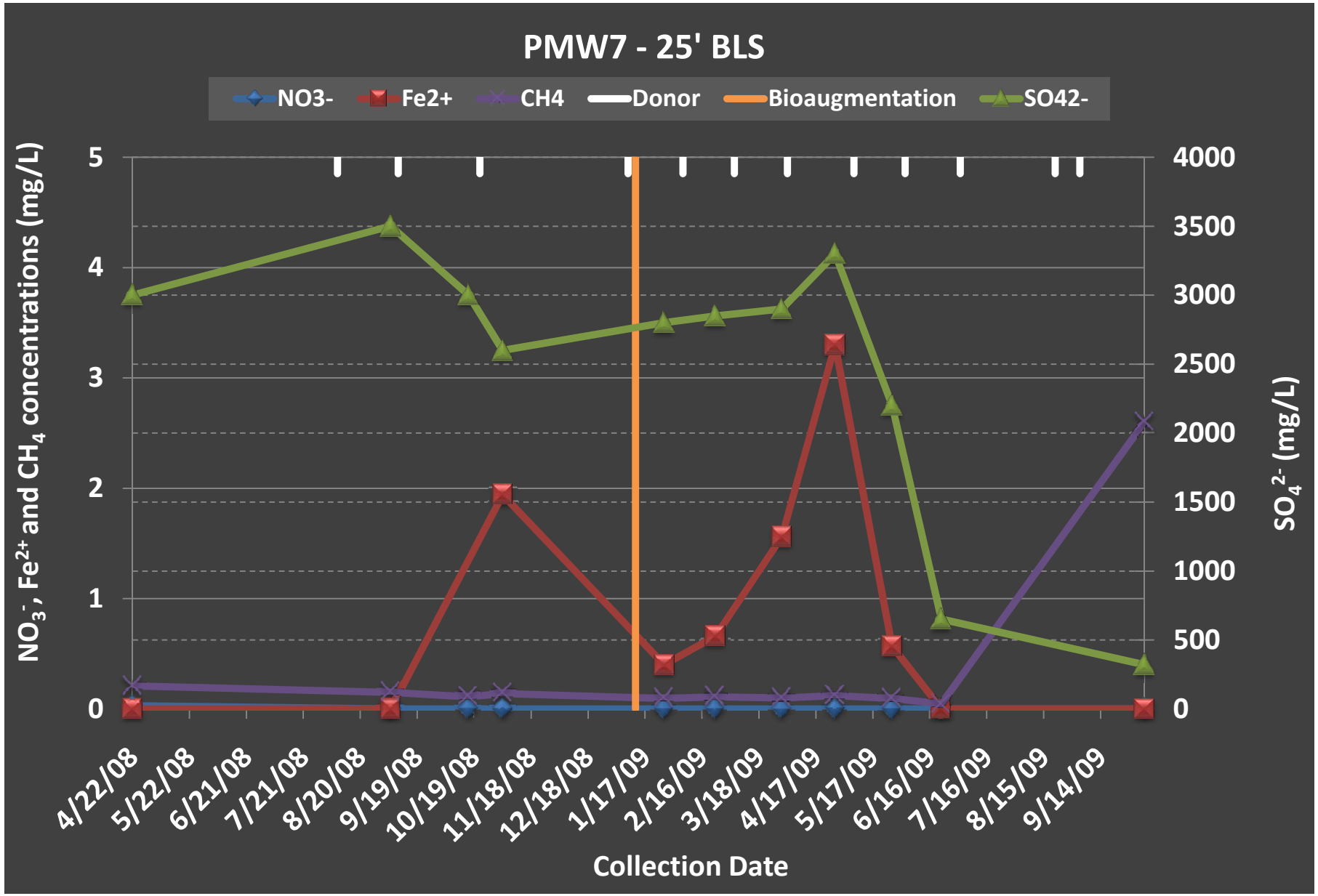

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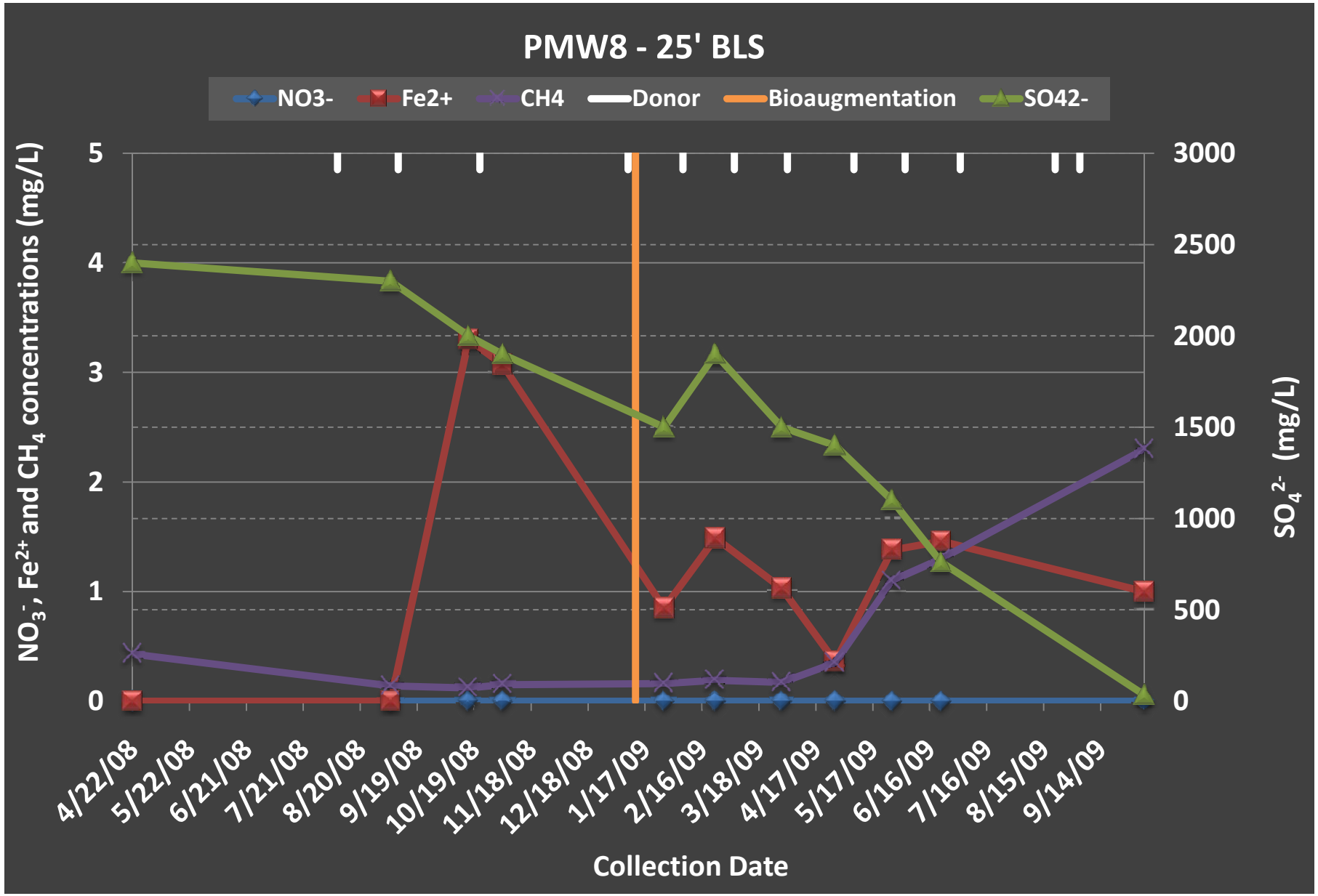

PMW8-25 RP EA, Electron Acceptors_Pas_Seal Beach_Oct 09.xlsx

Seal Beach
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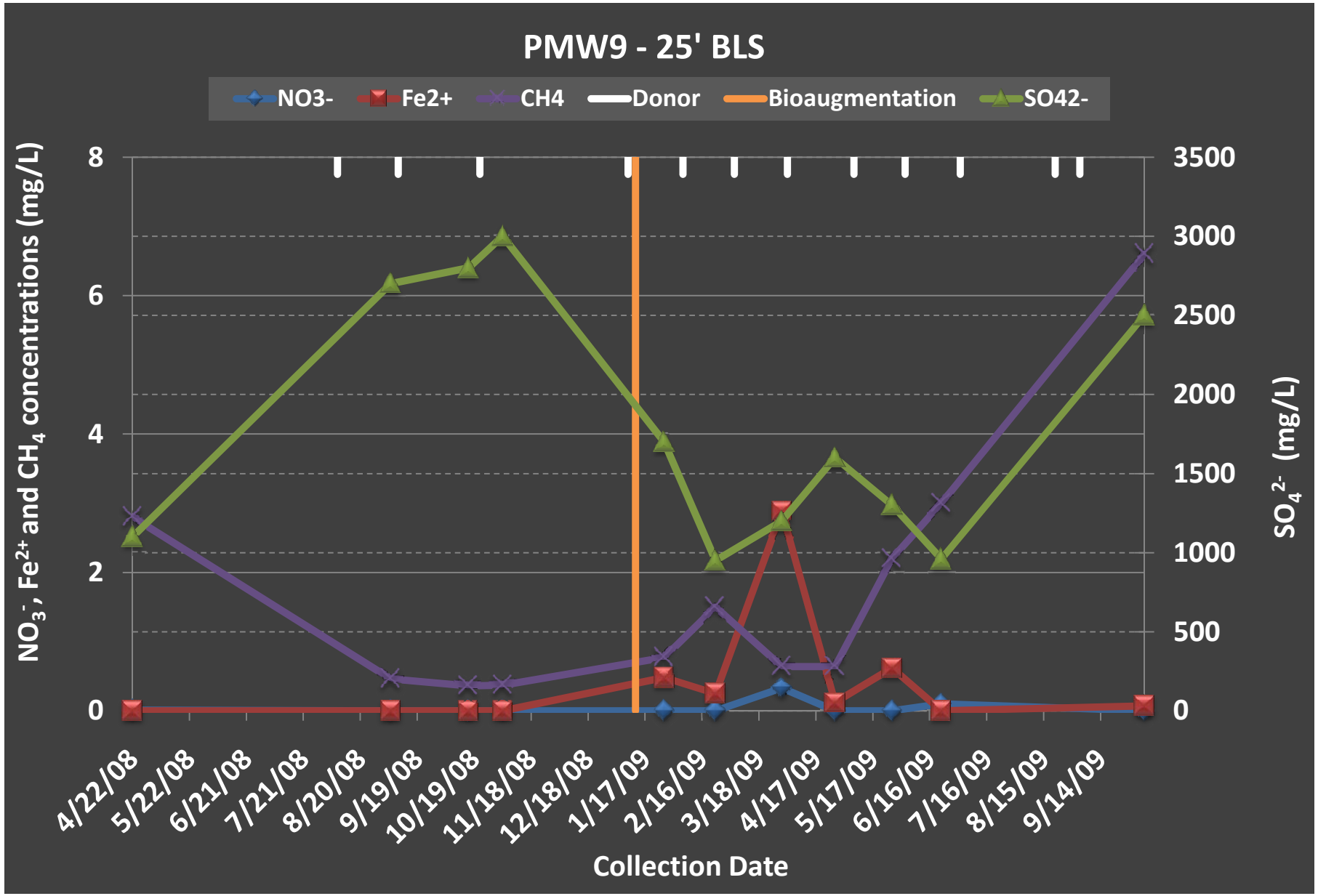
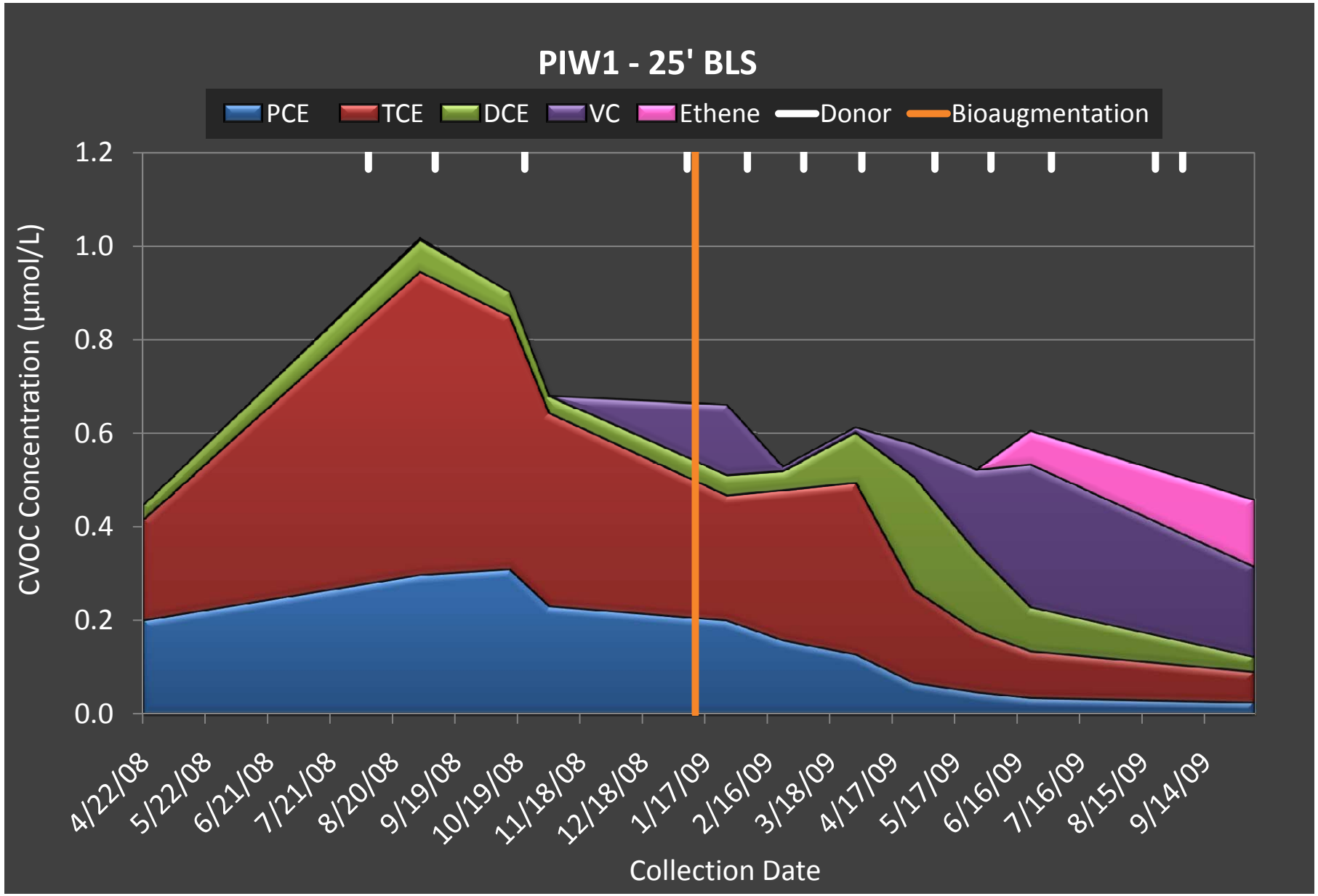


CVOCs Molar Concentrations

Seal Beach
Groundwater Bioaugmentation



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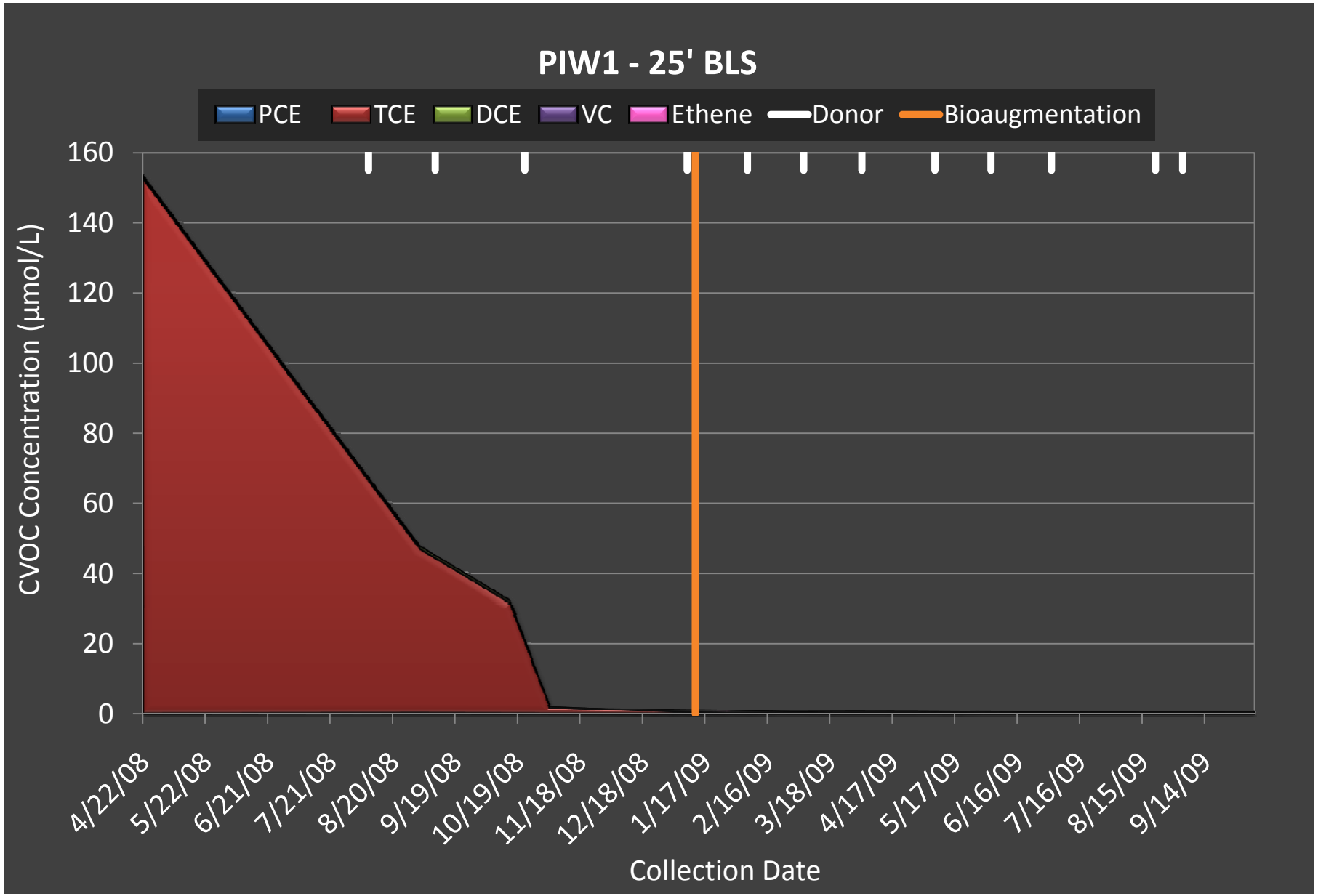

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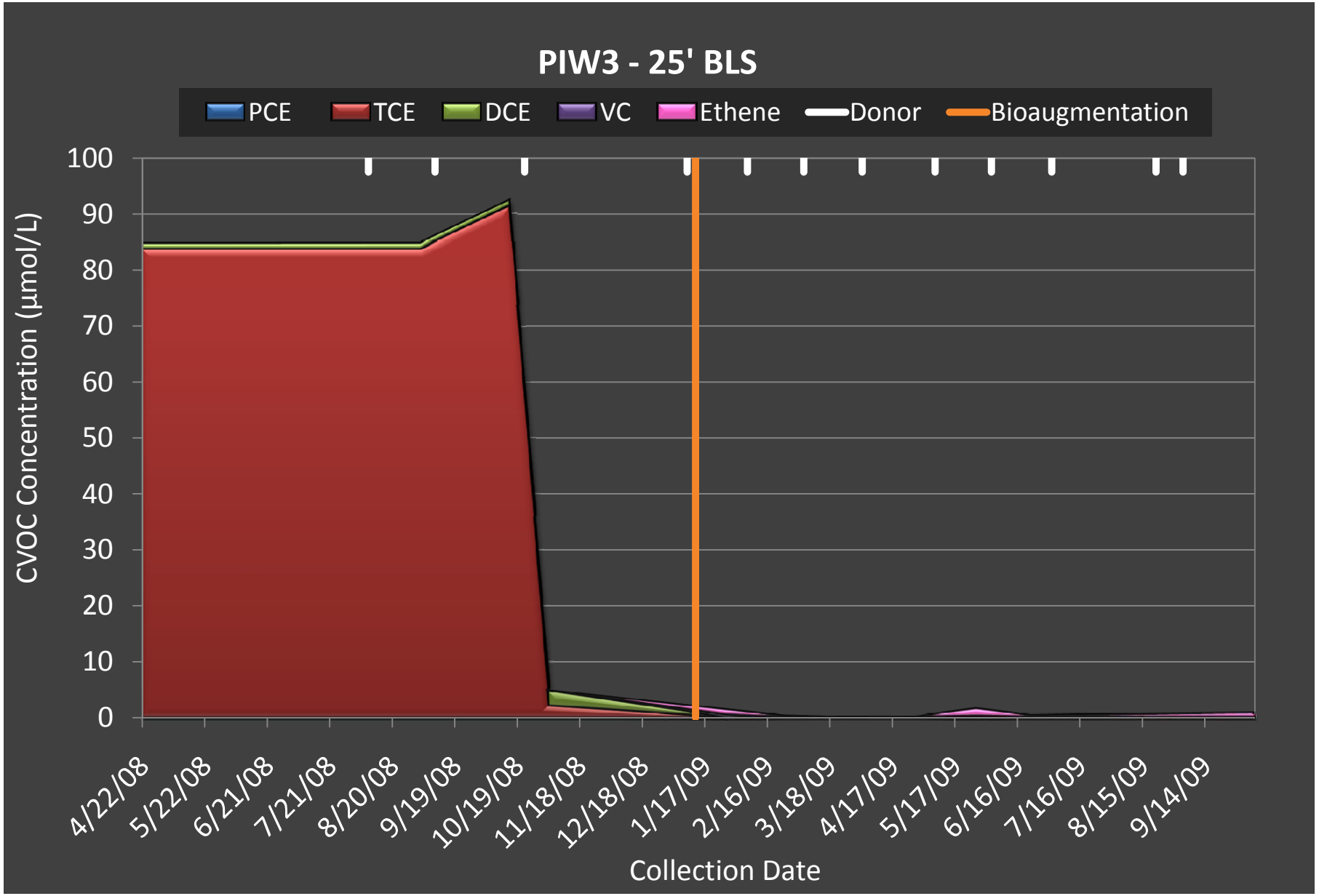

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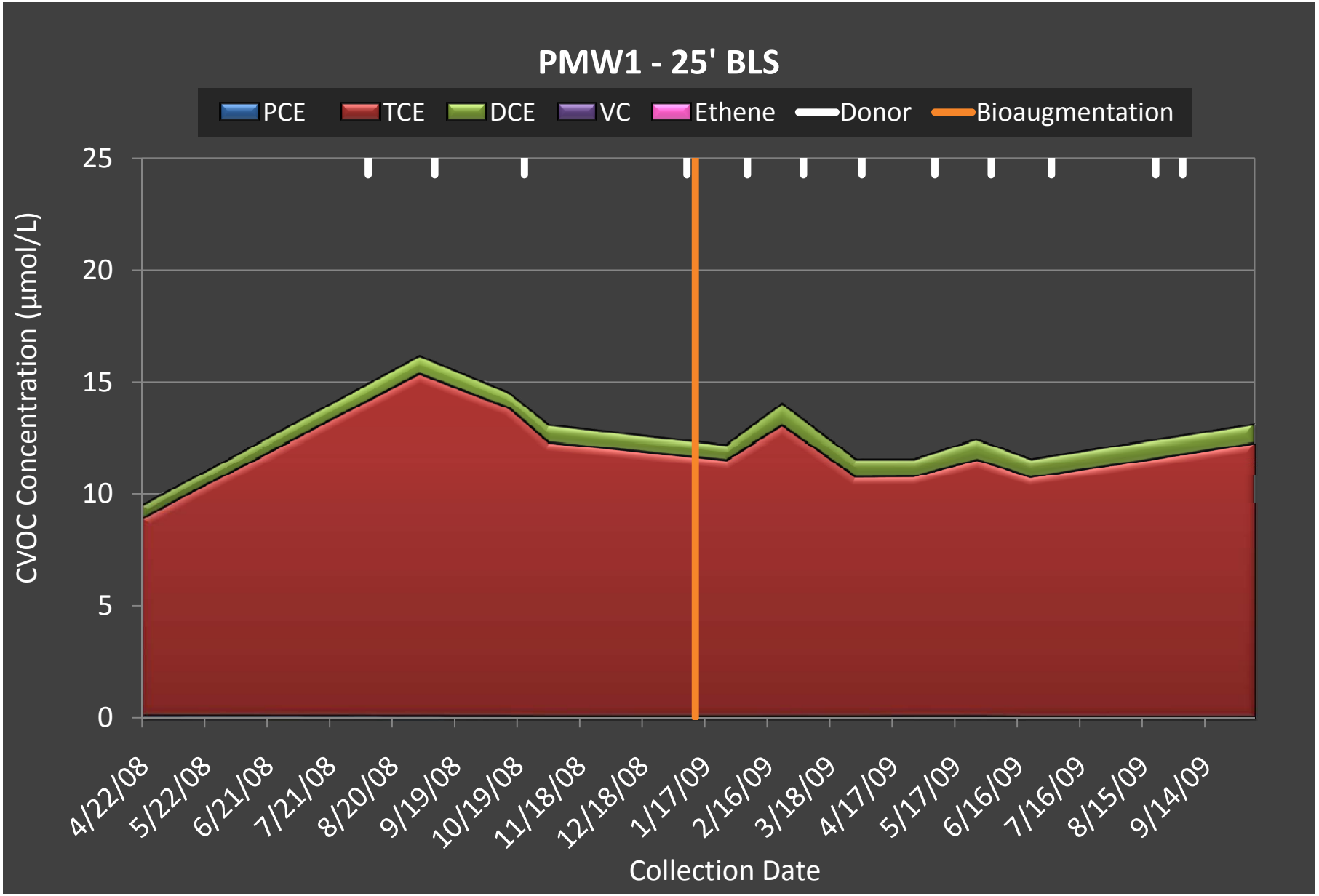

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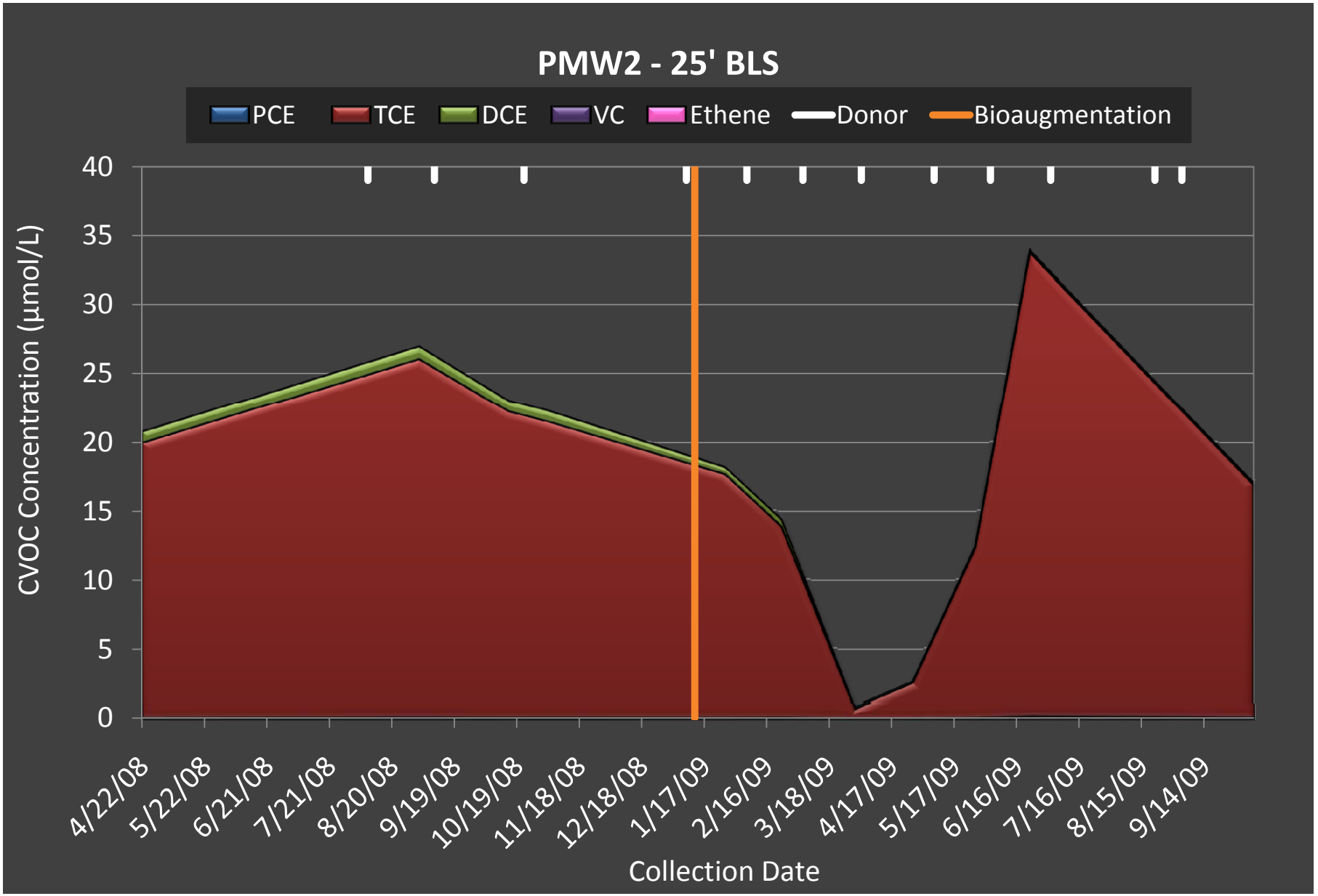
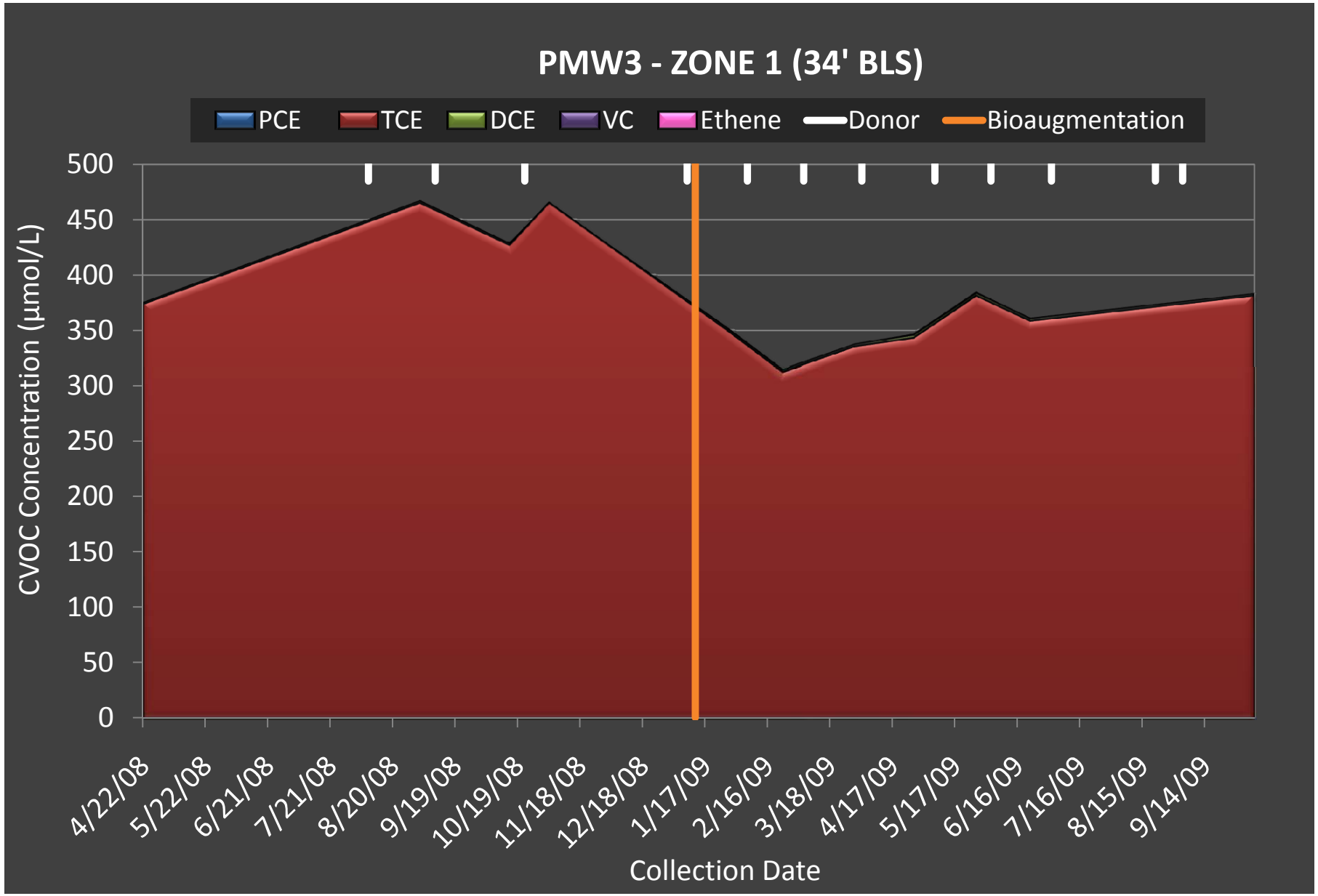
Seal Beach
Groundwater Bioaugmentation

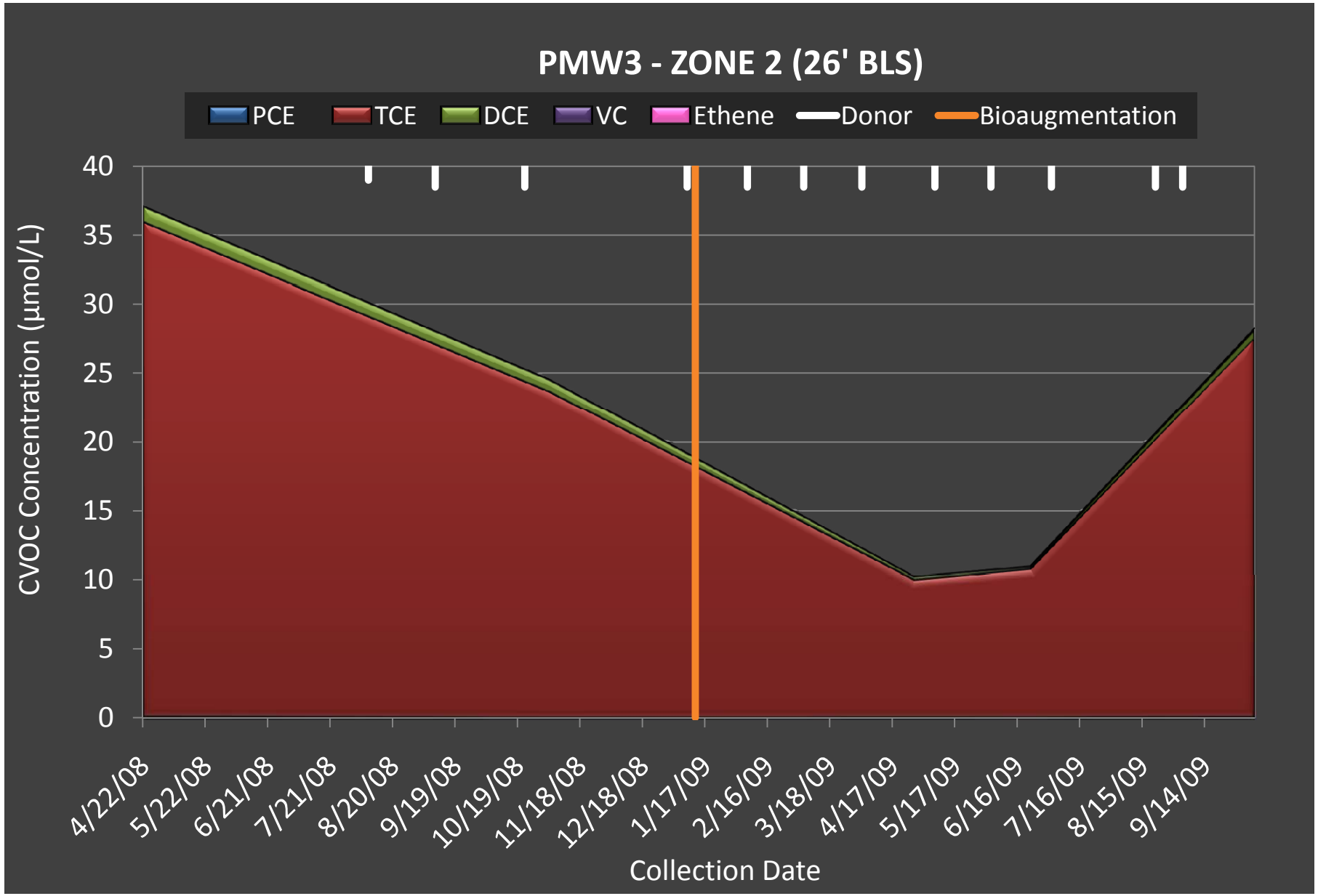


PMW2-25, Dechlorination_molar_Pas_Seal Beach_Oct 2009.xlsx

Seal Beach
Groundwater Bioaugmentation



Seal Beach
Groundwater Bioaugmentation



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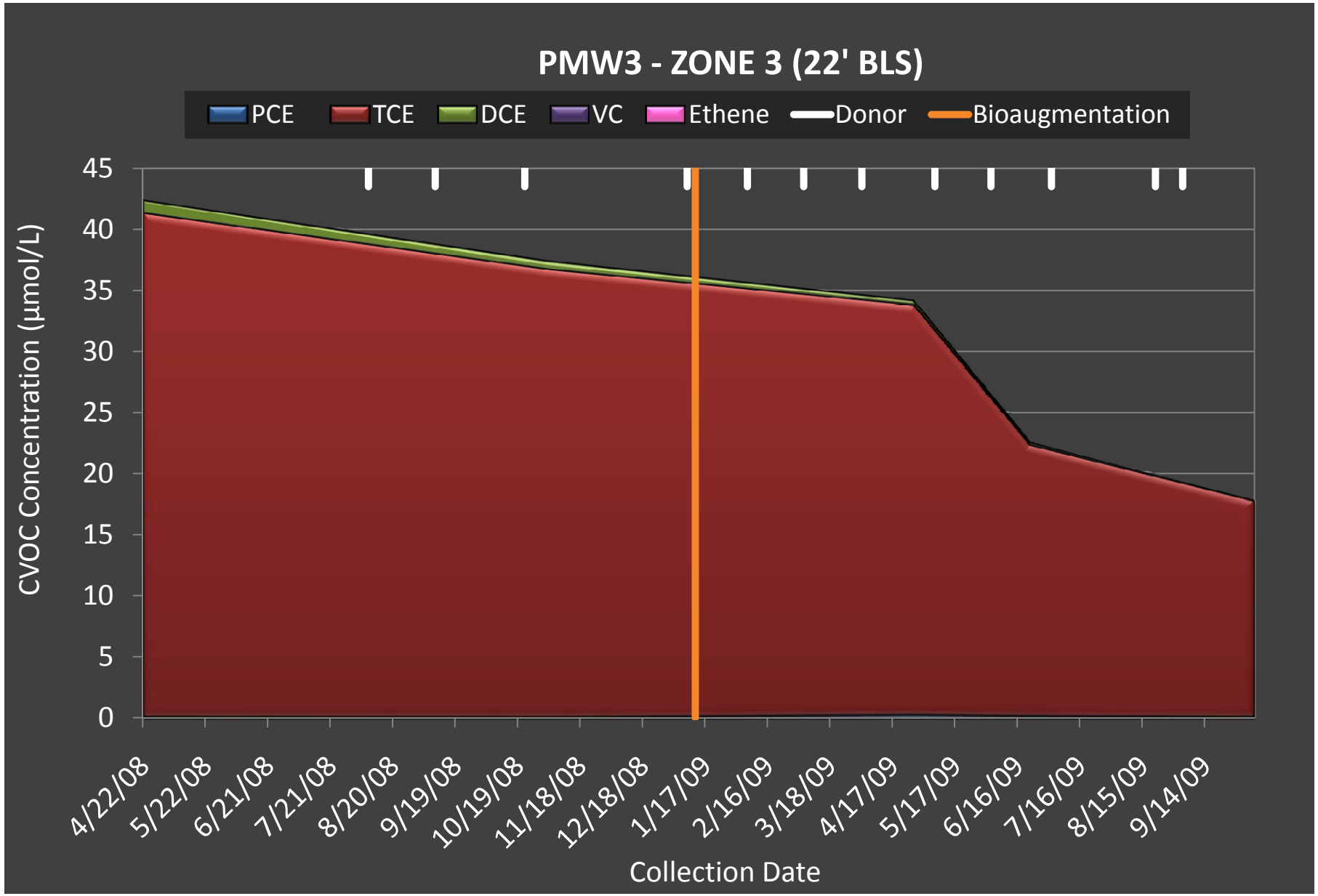

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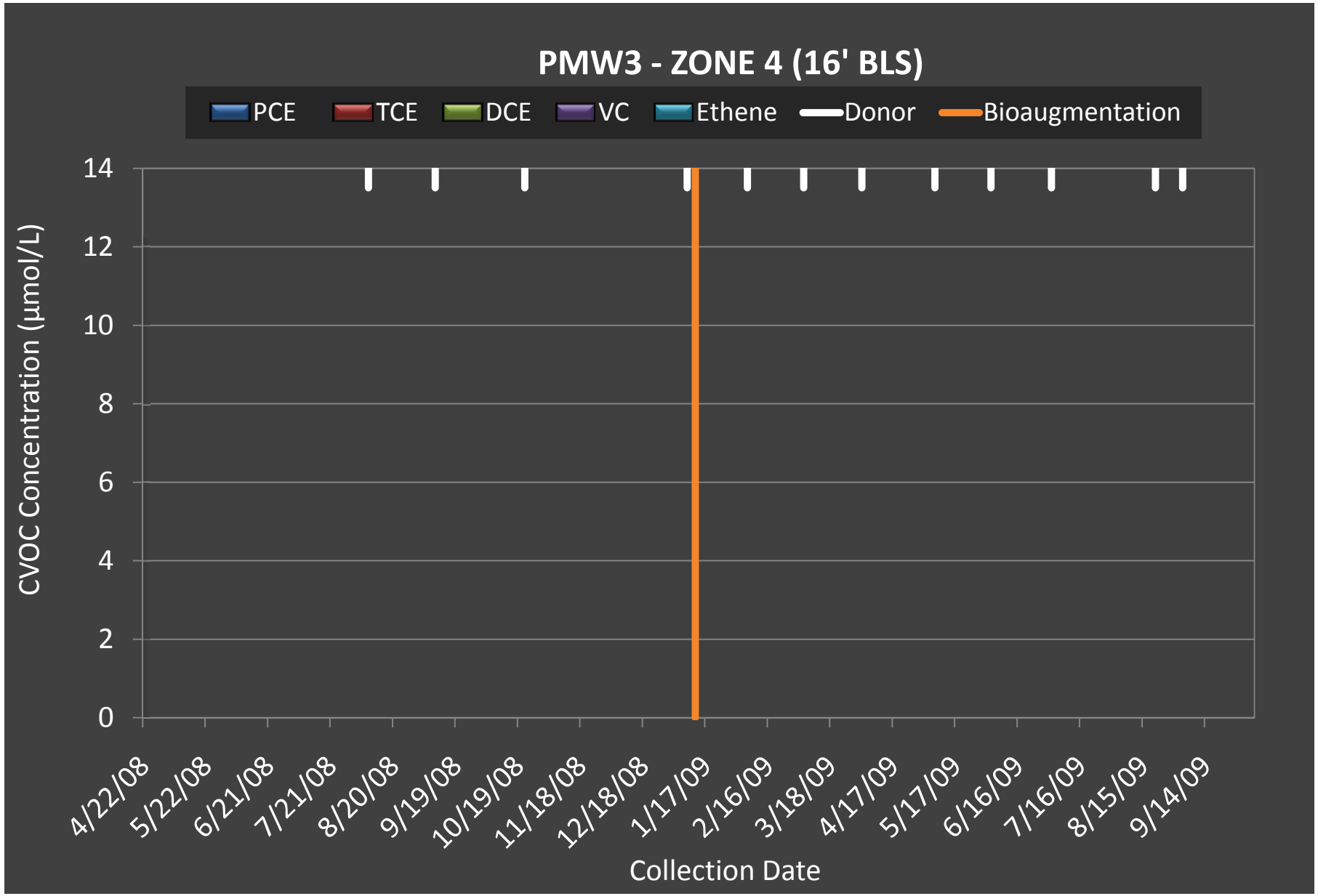

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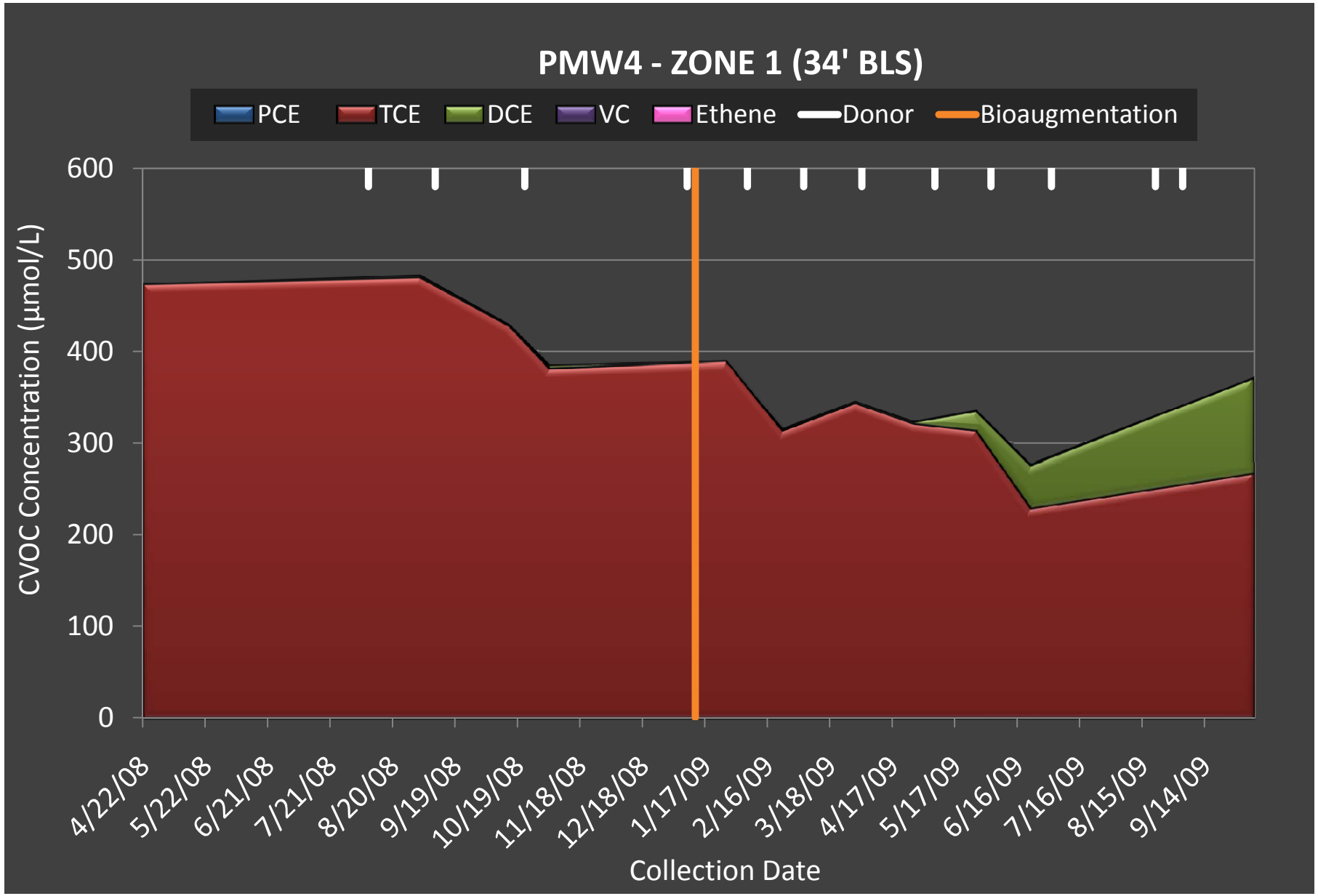

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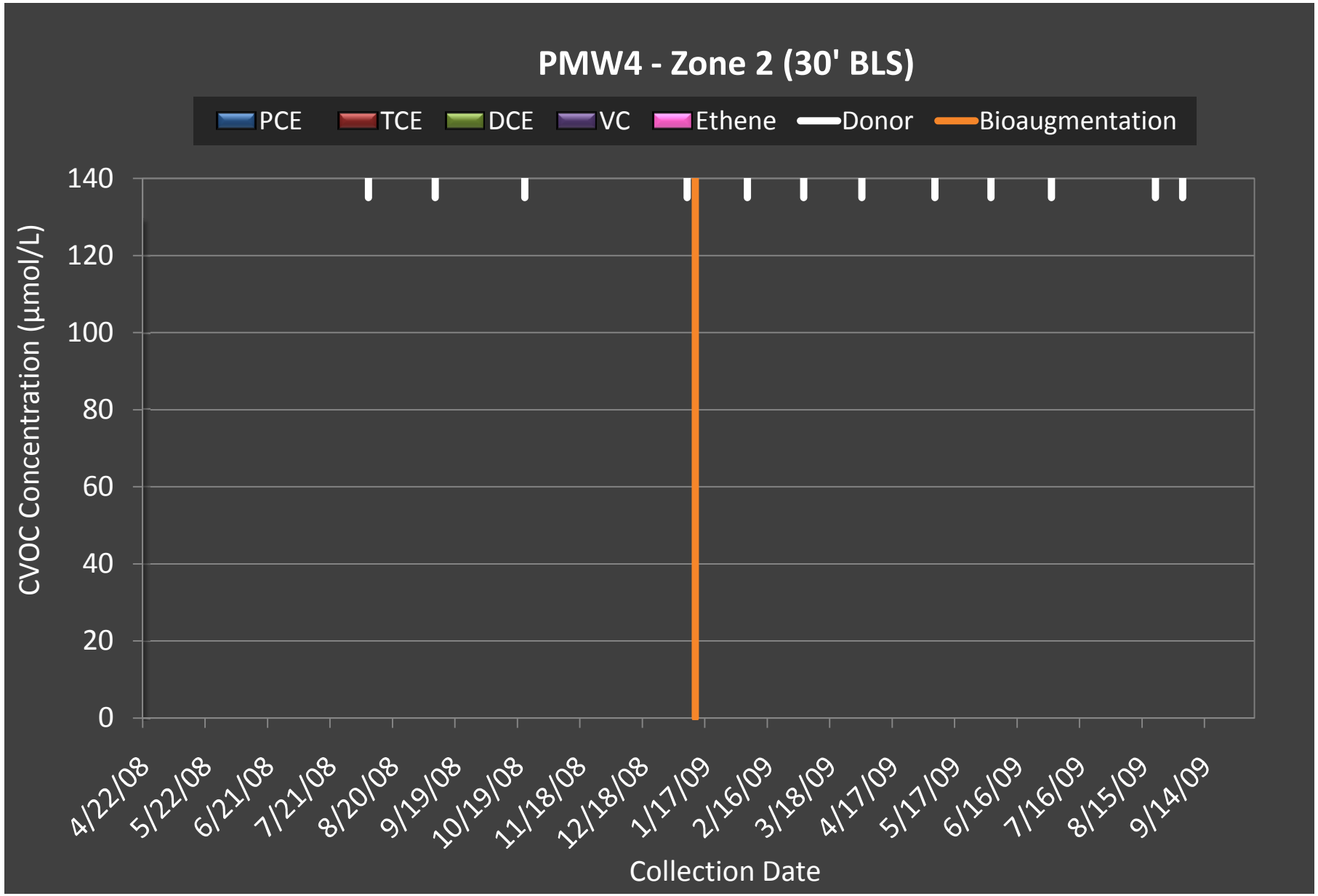

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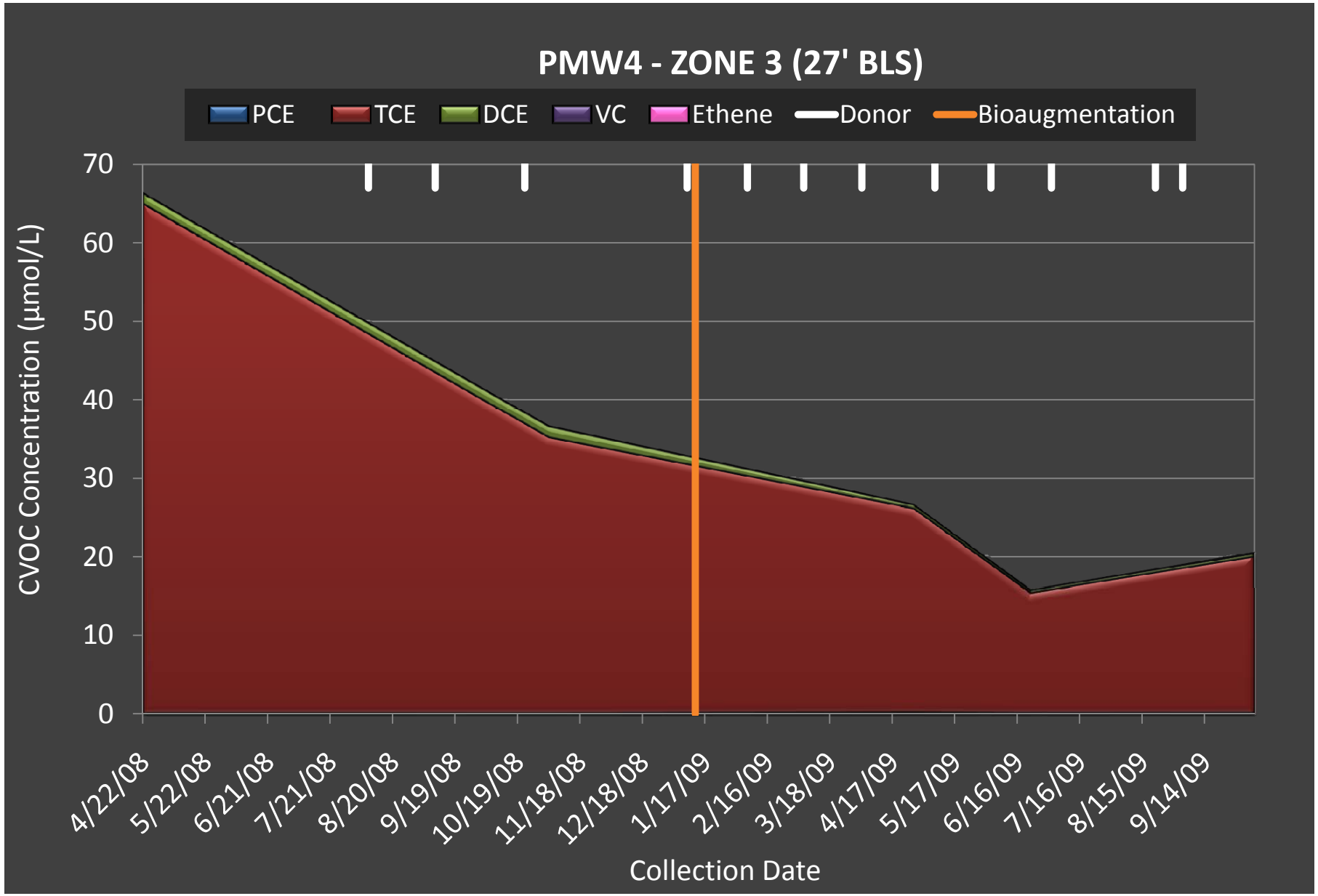

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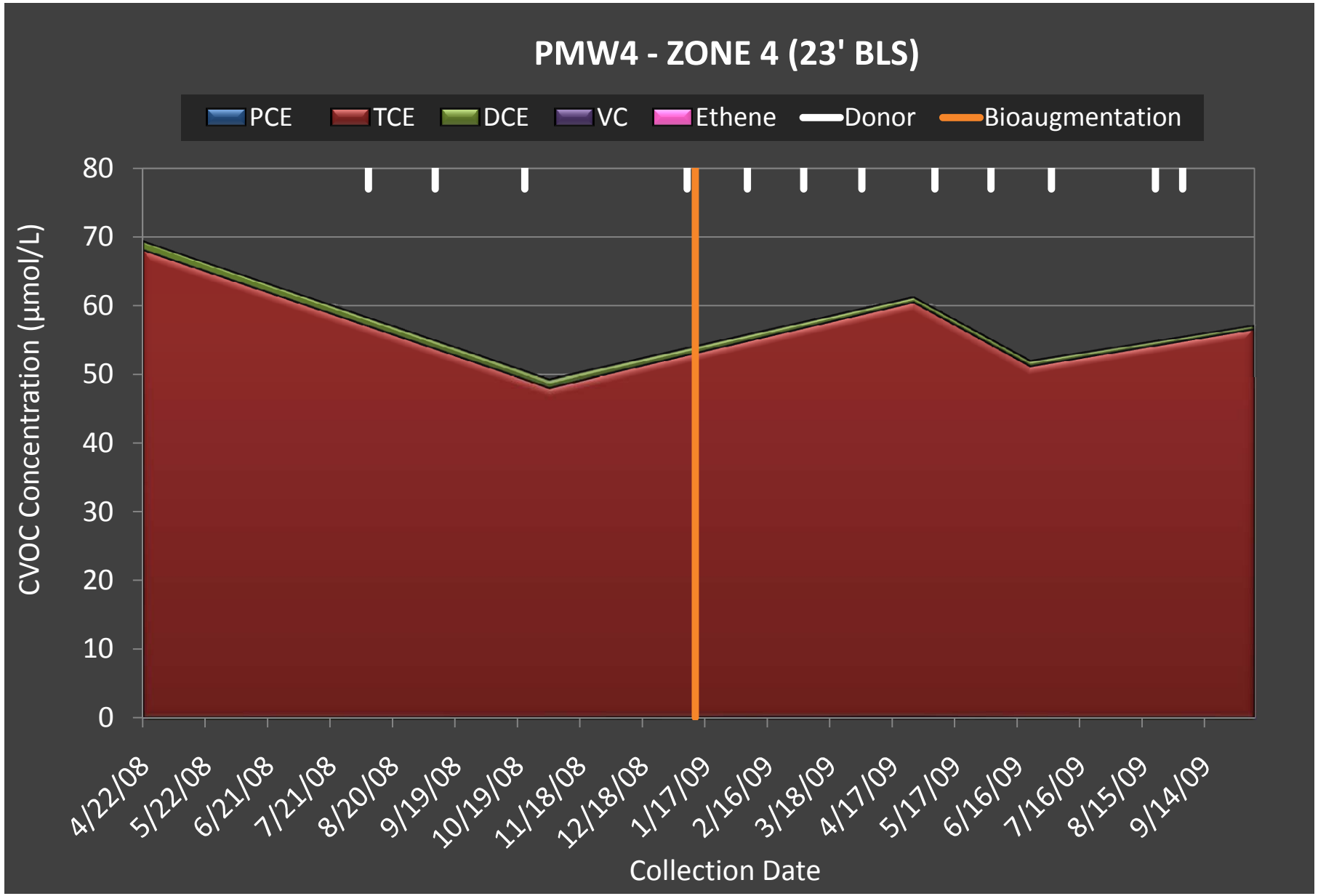

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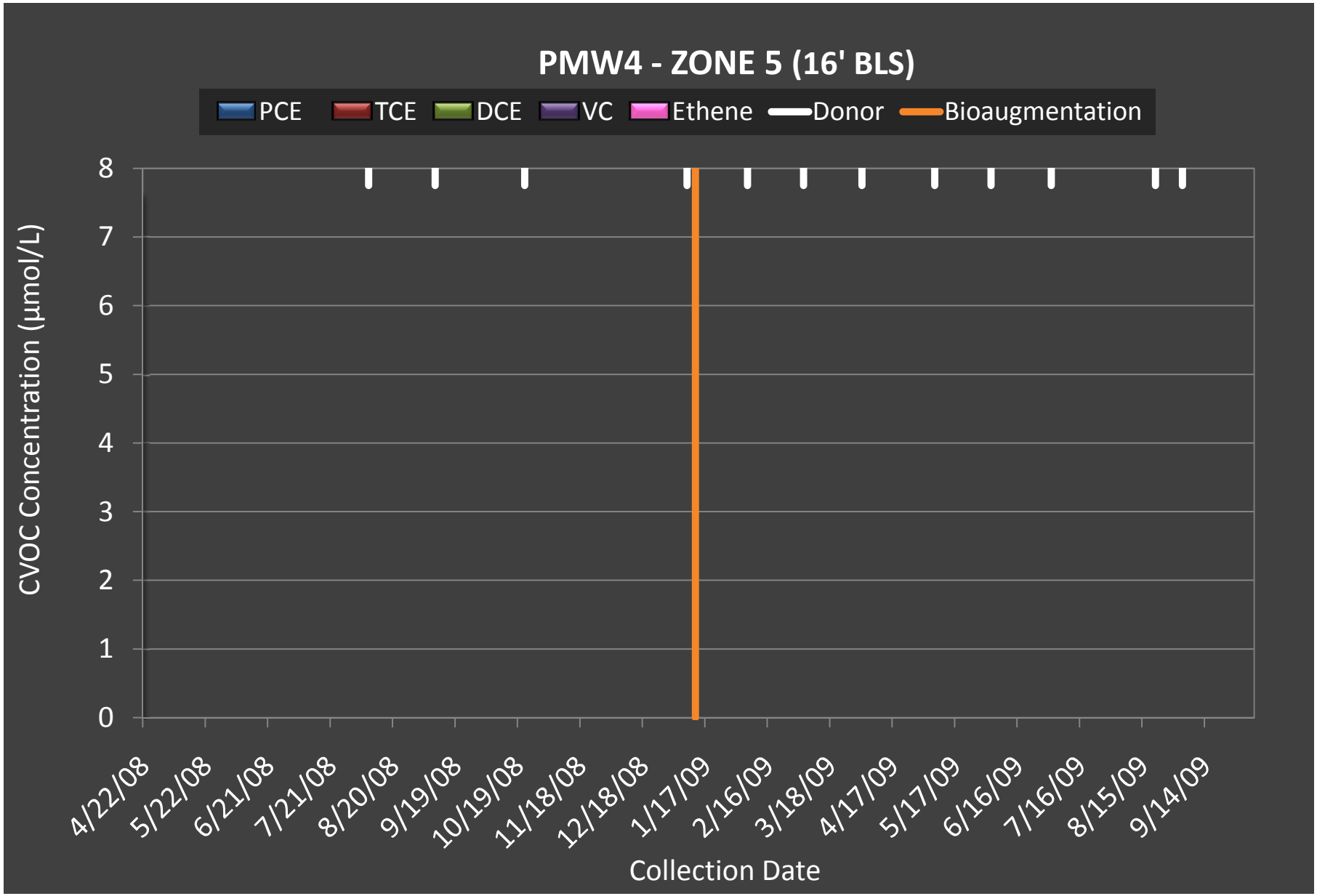

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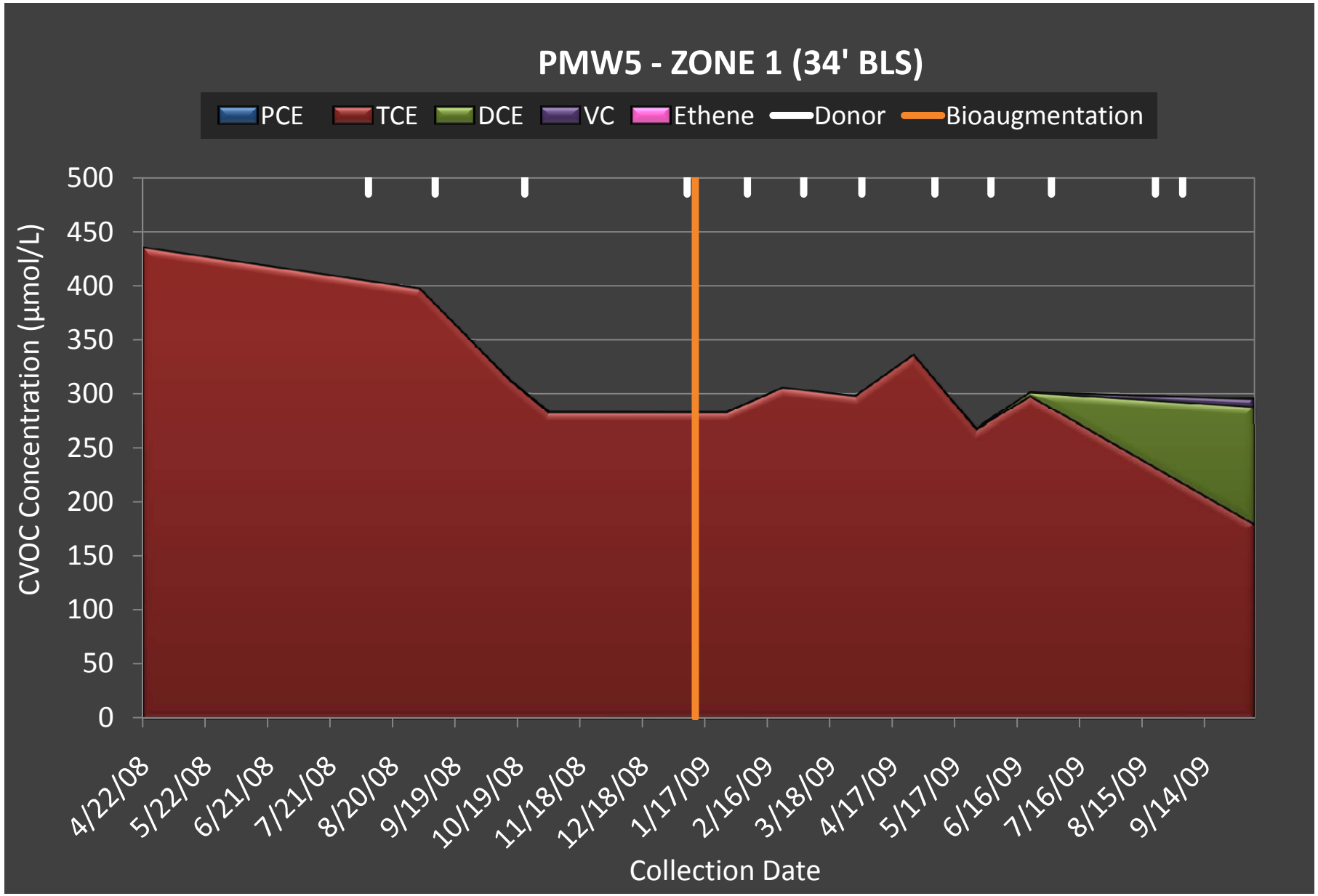

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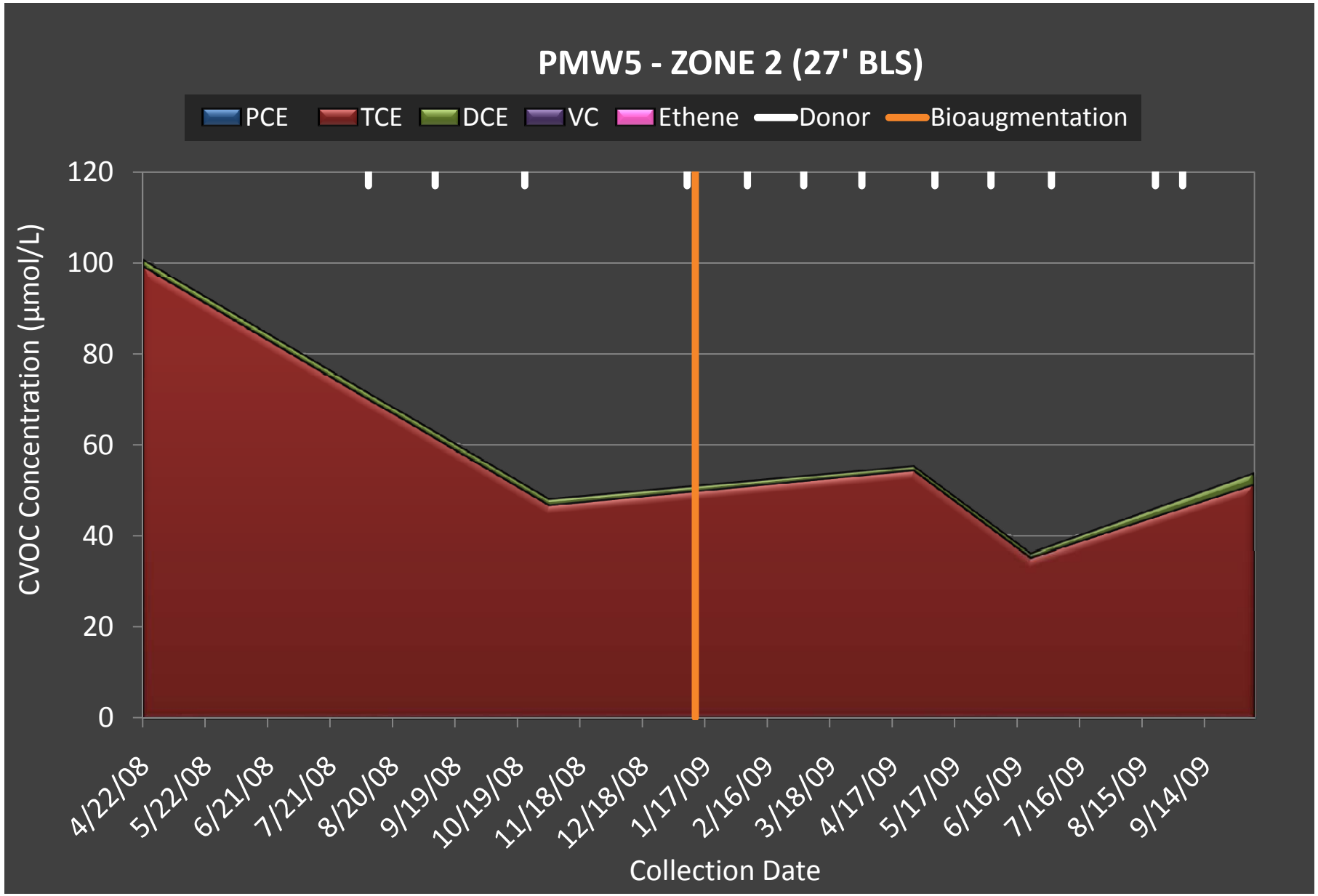

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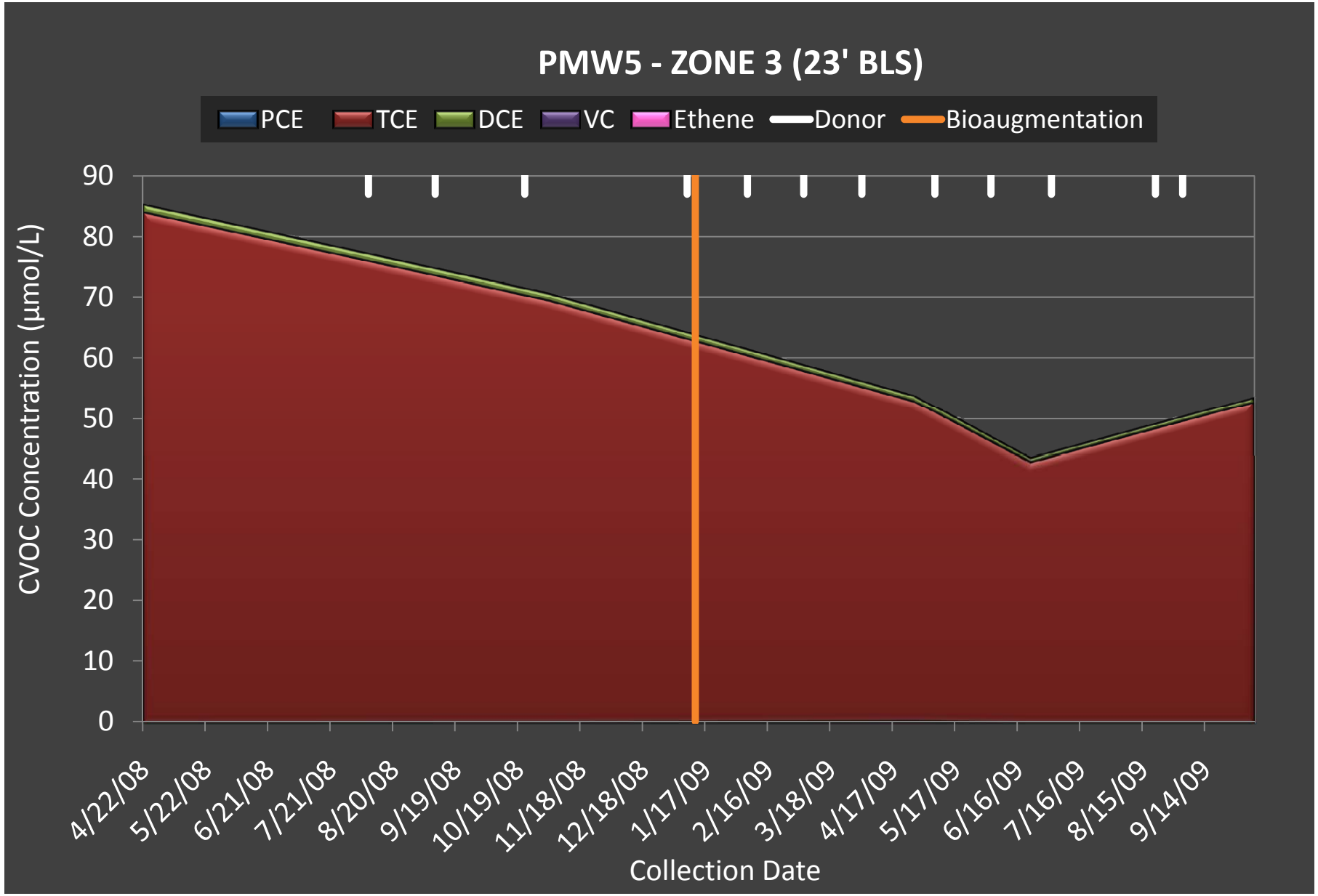

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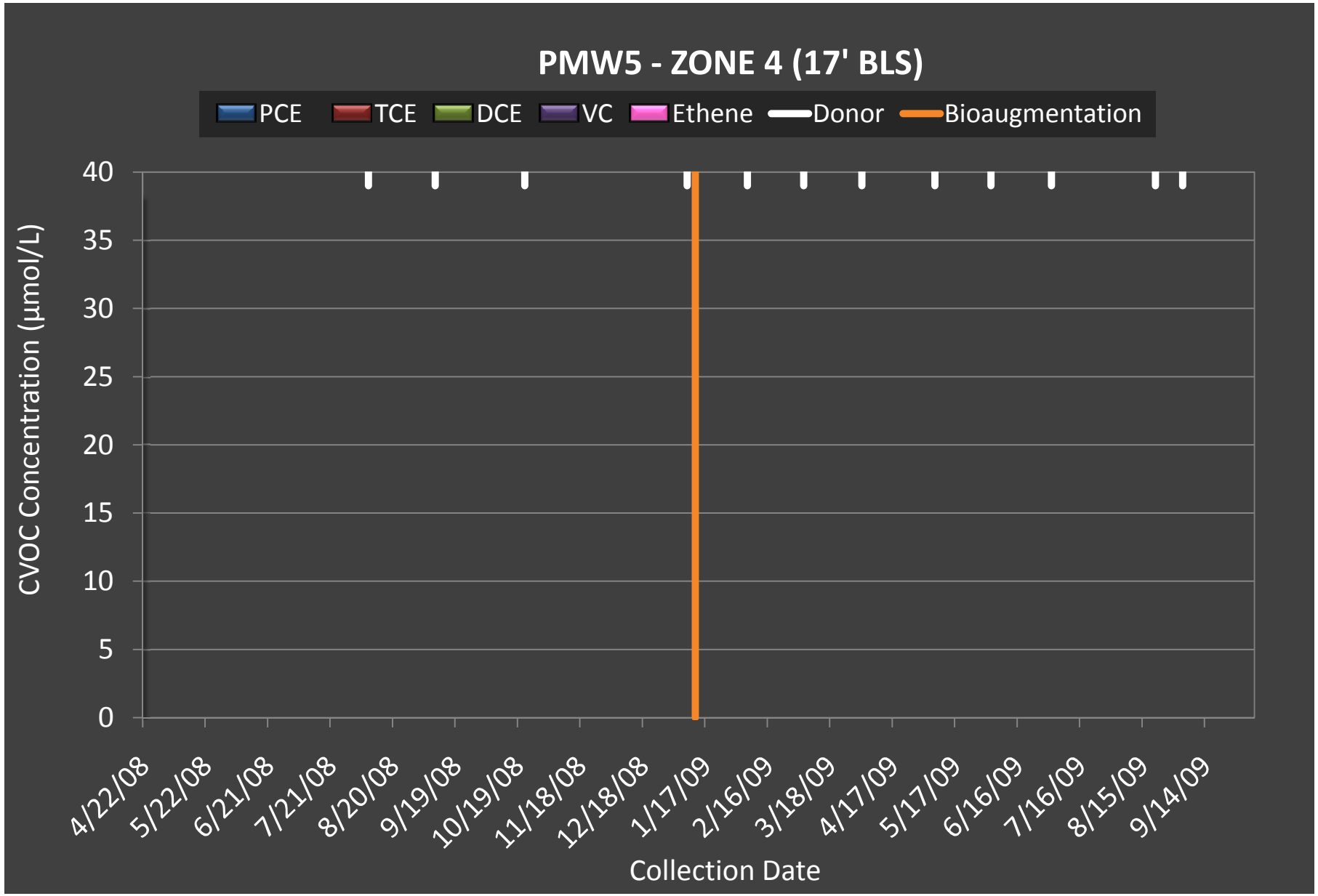

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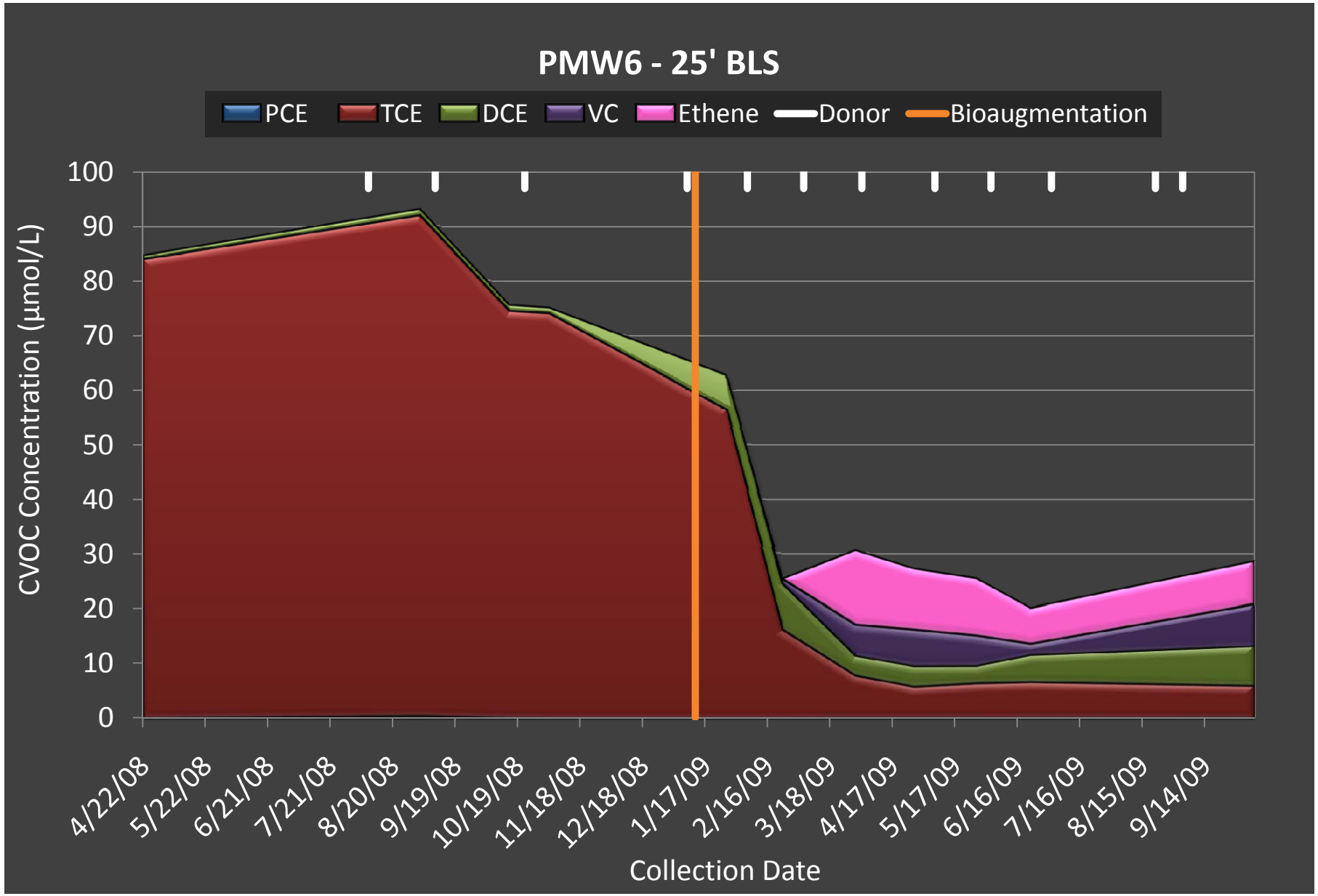

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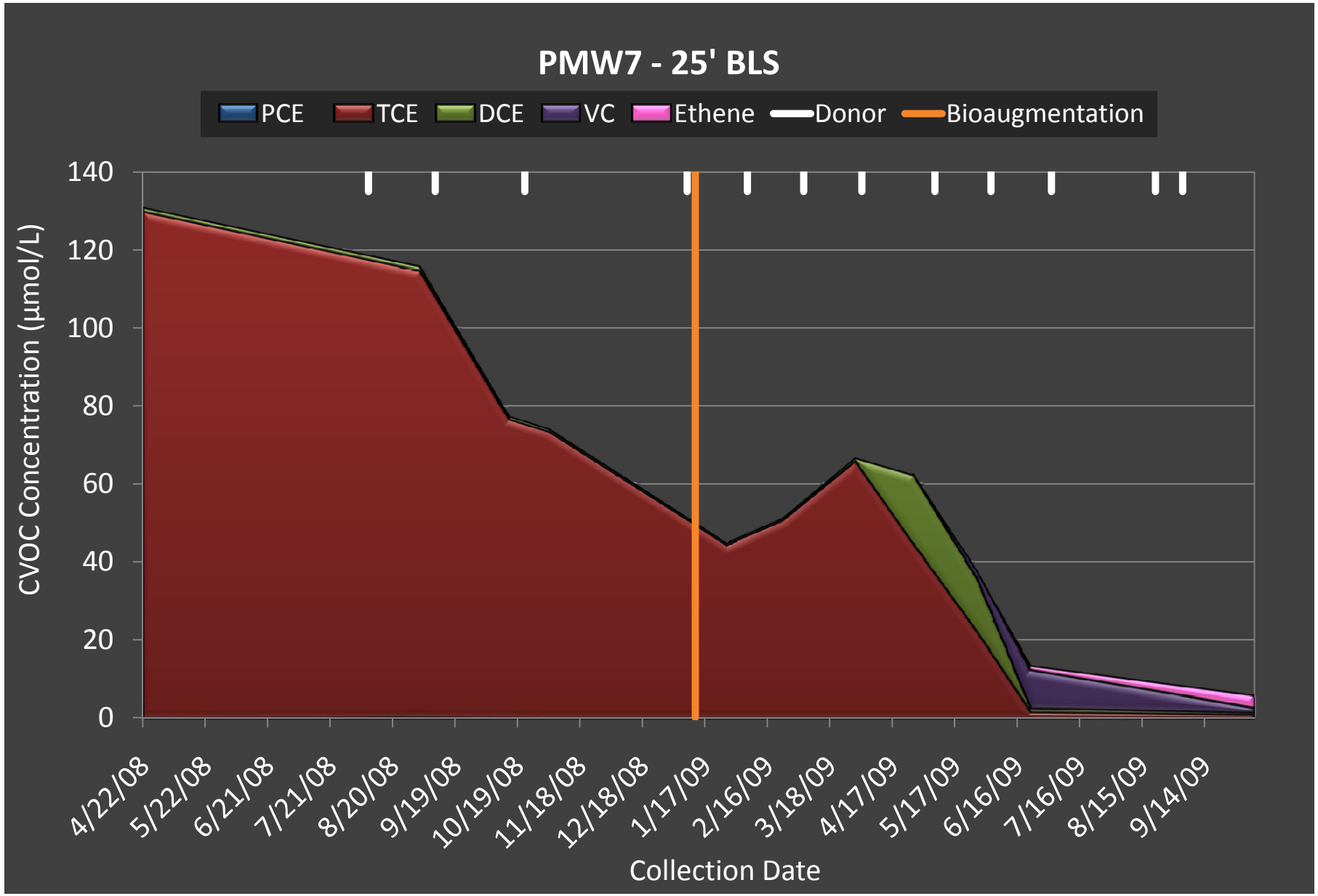

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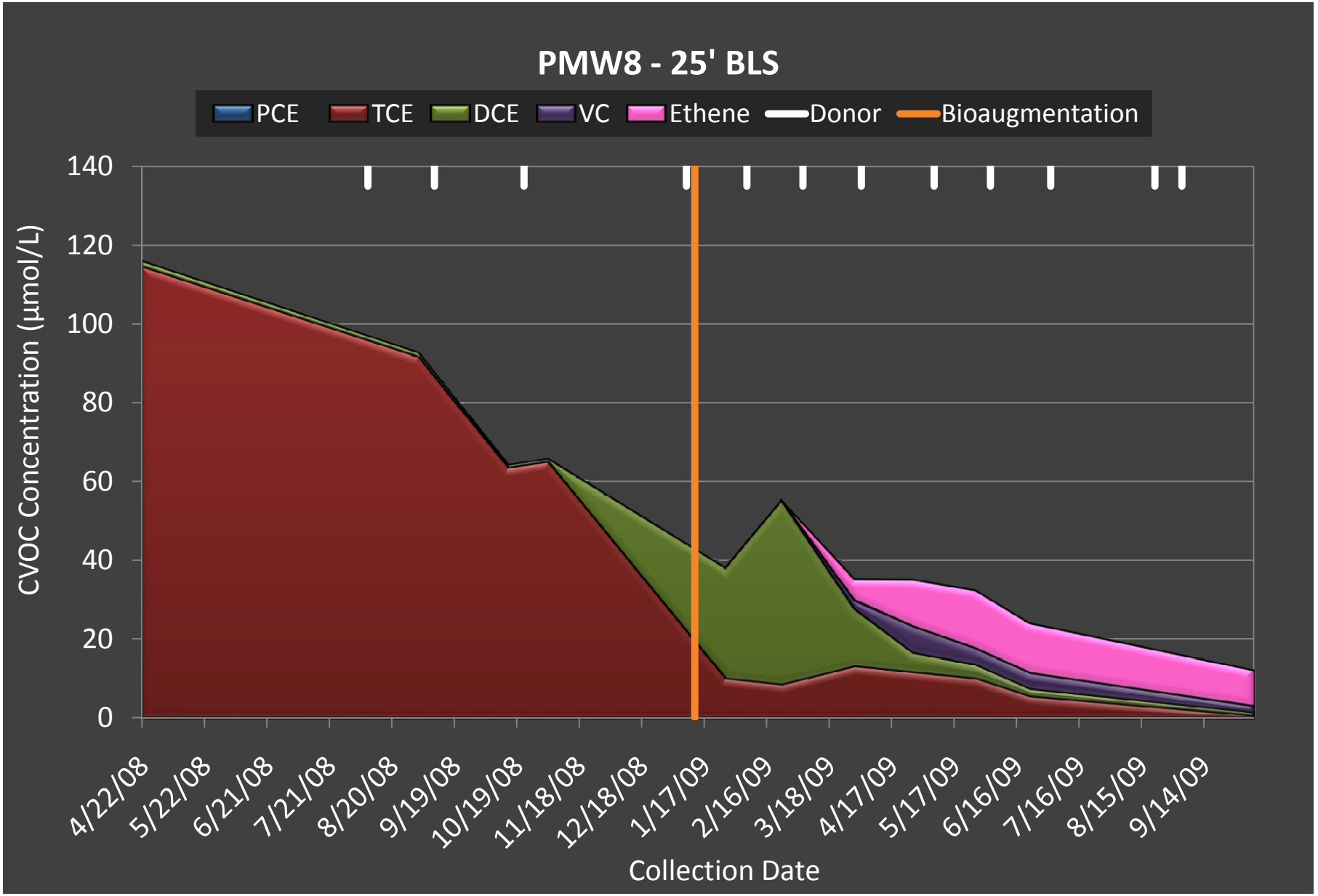

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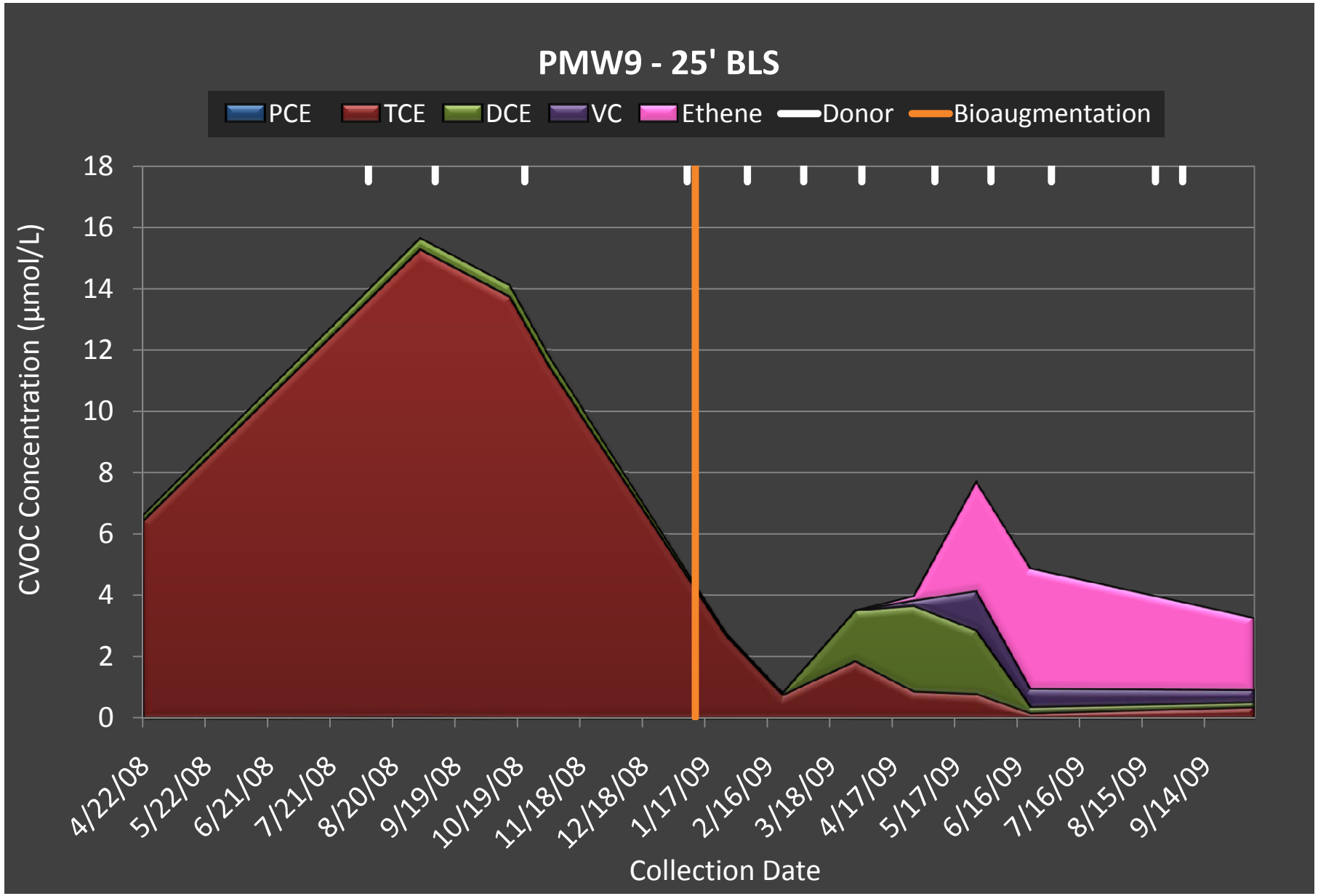

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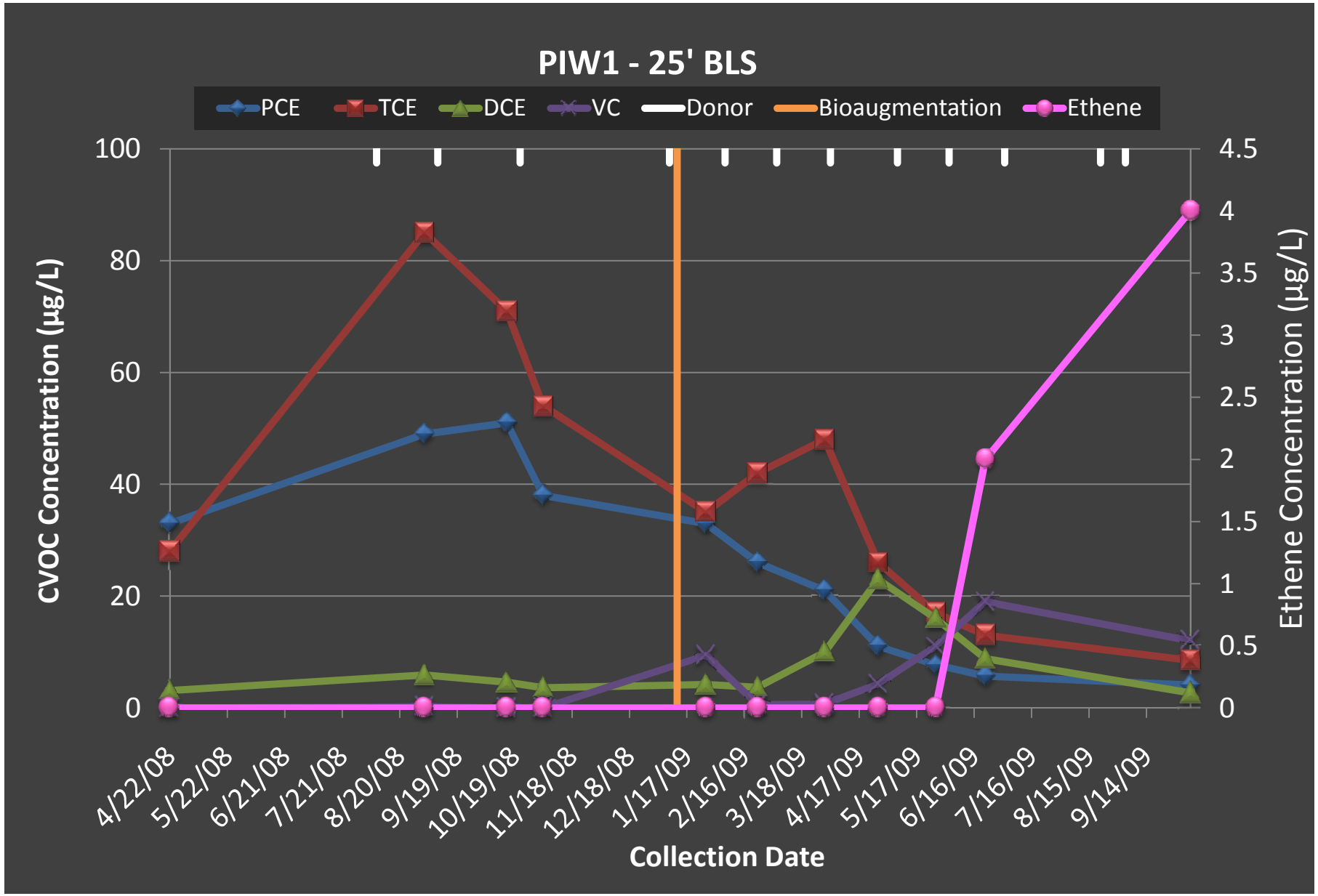
CVOCs Mass Concentrations

Seal Beach
Groundwater Bioaugmentation



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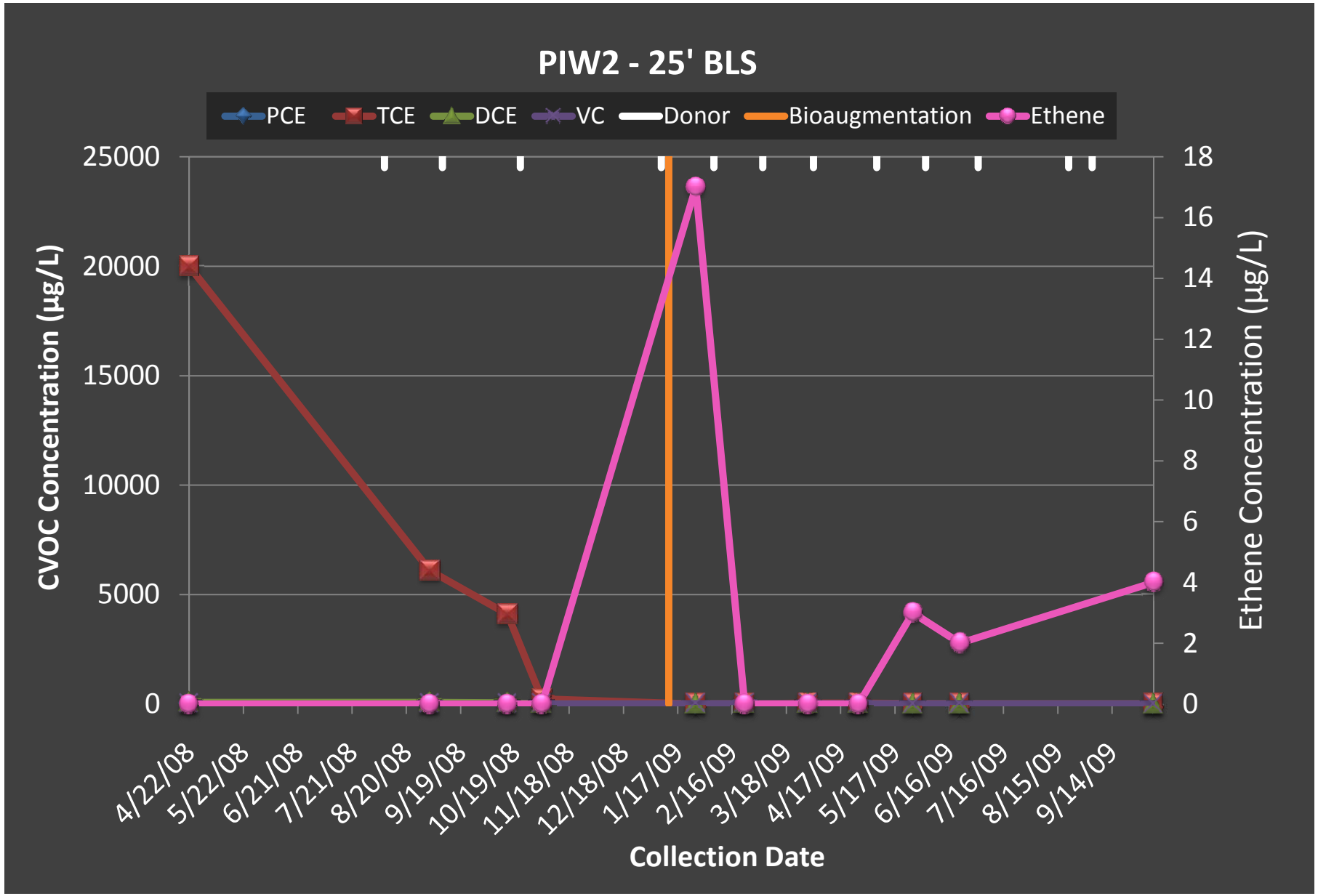

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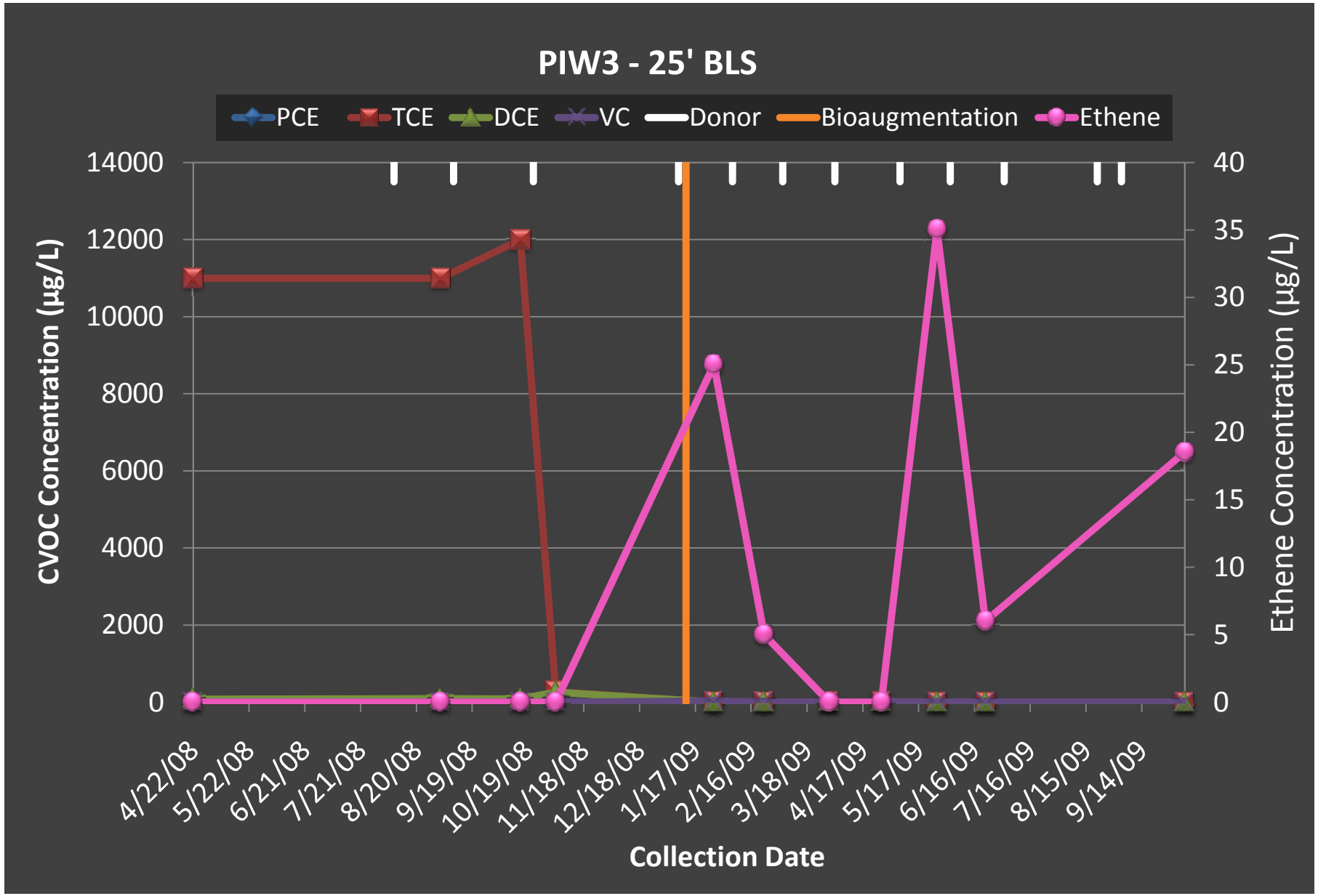

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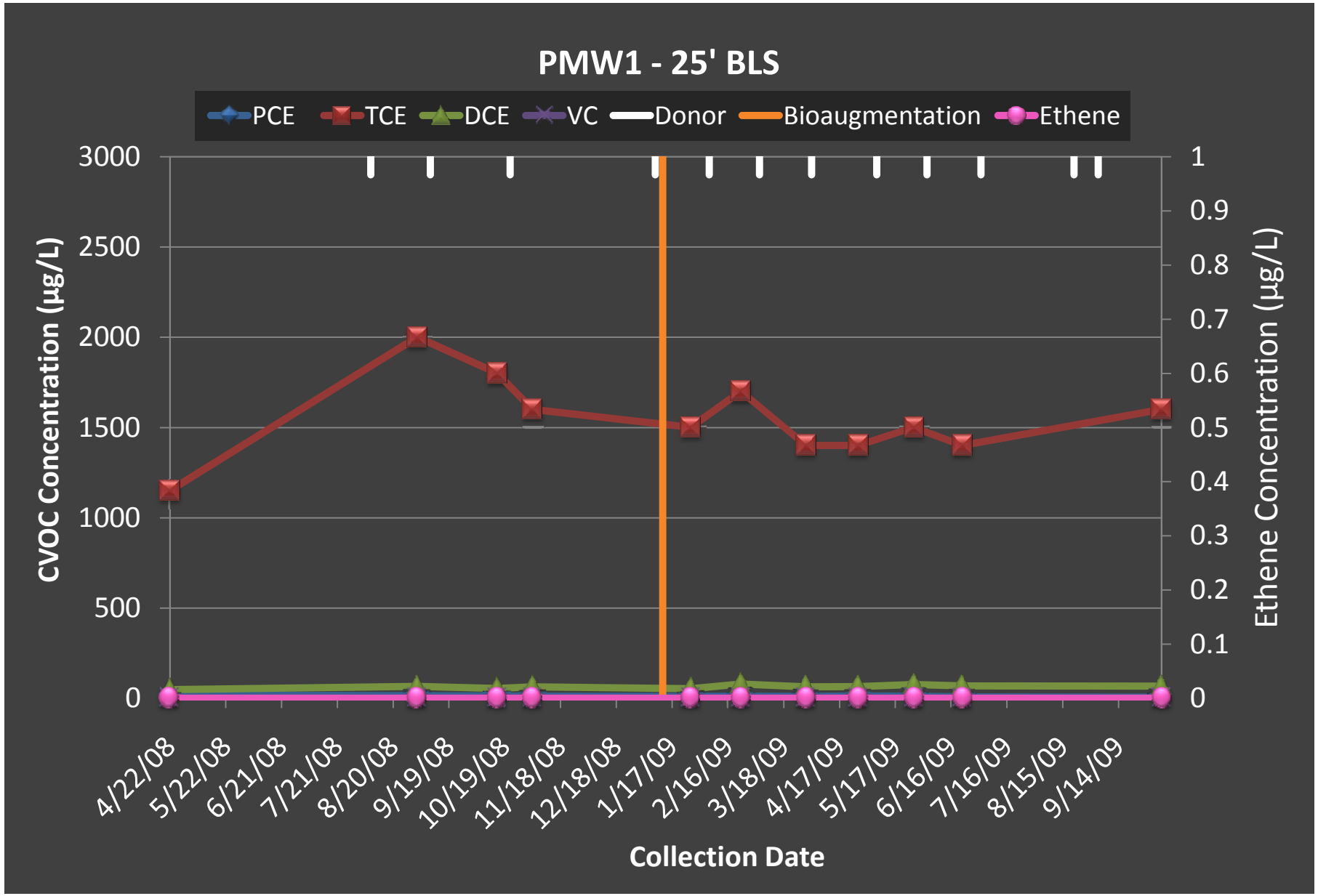

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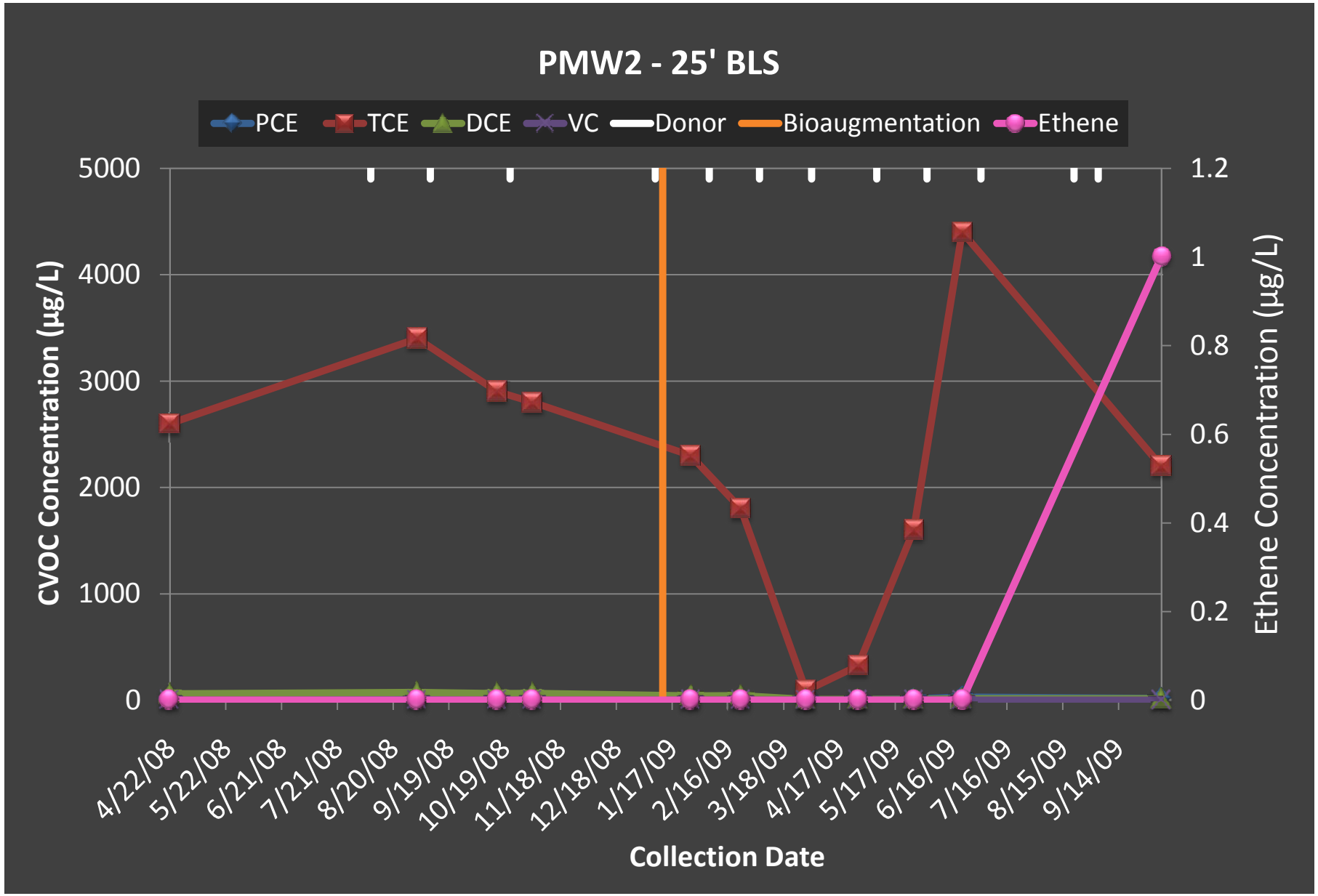

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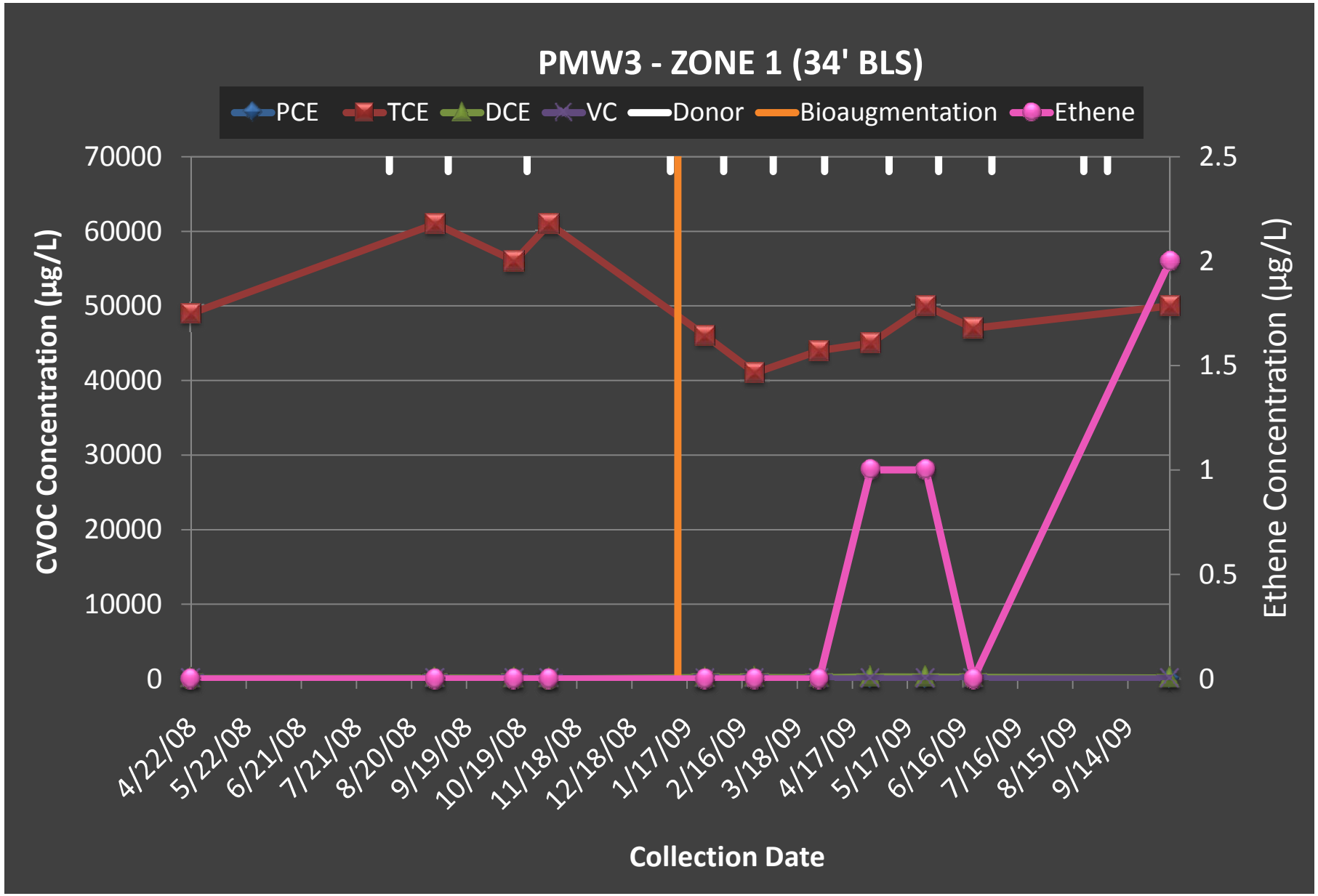

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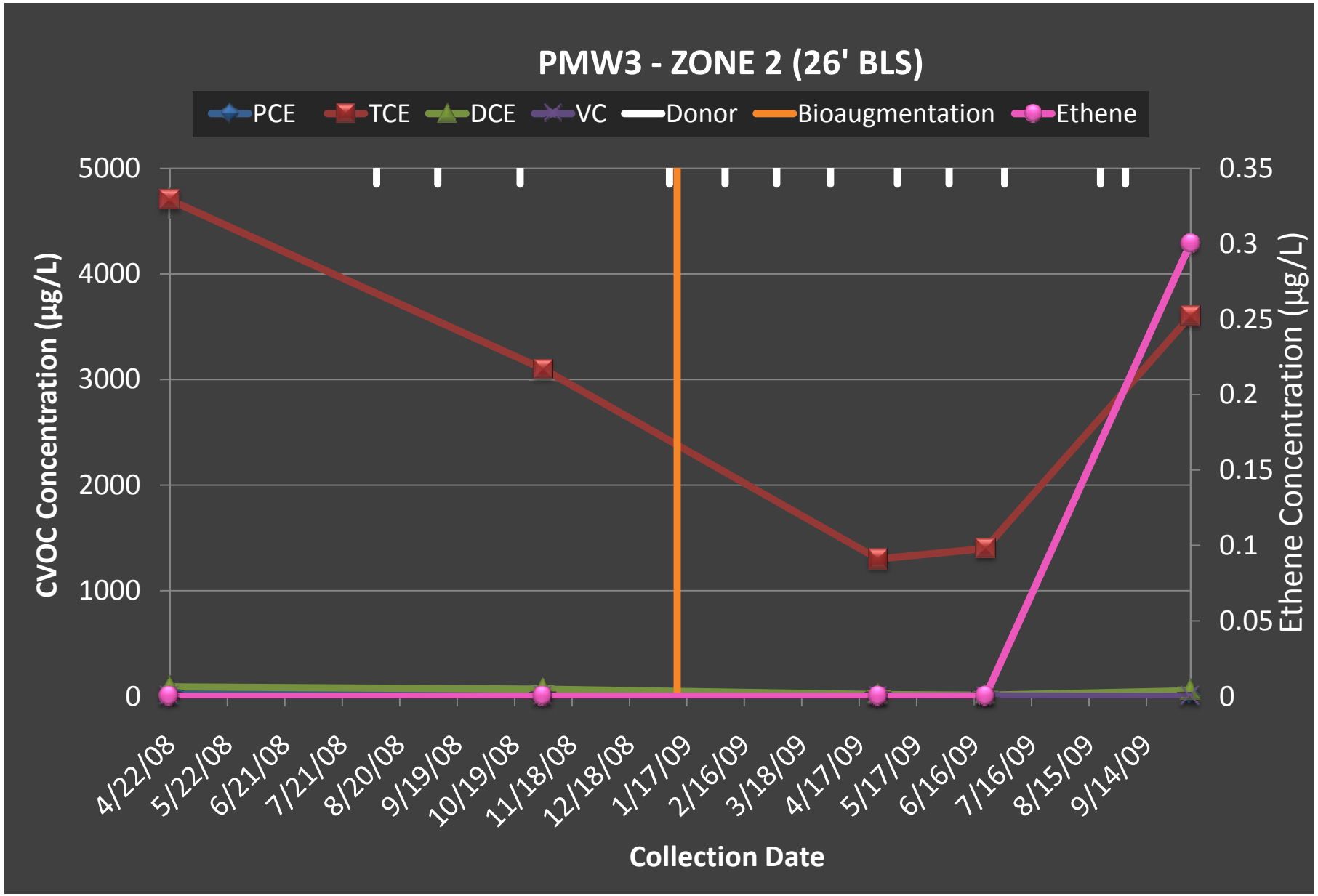

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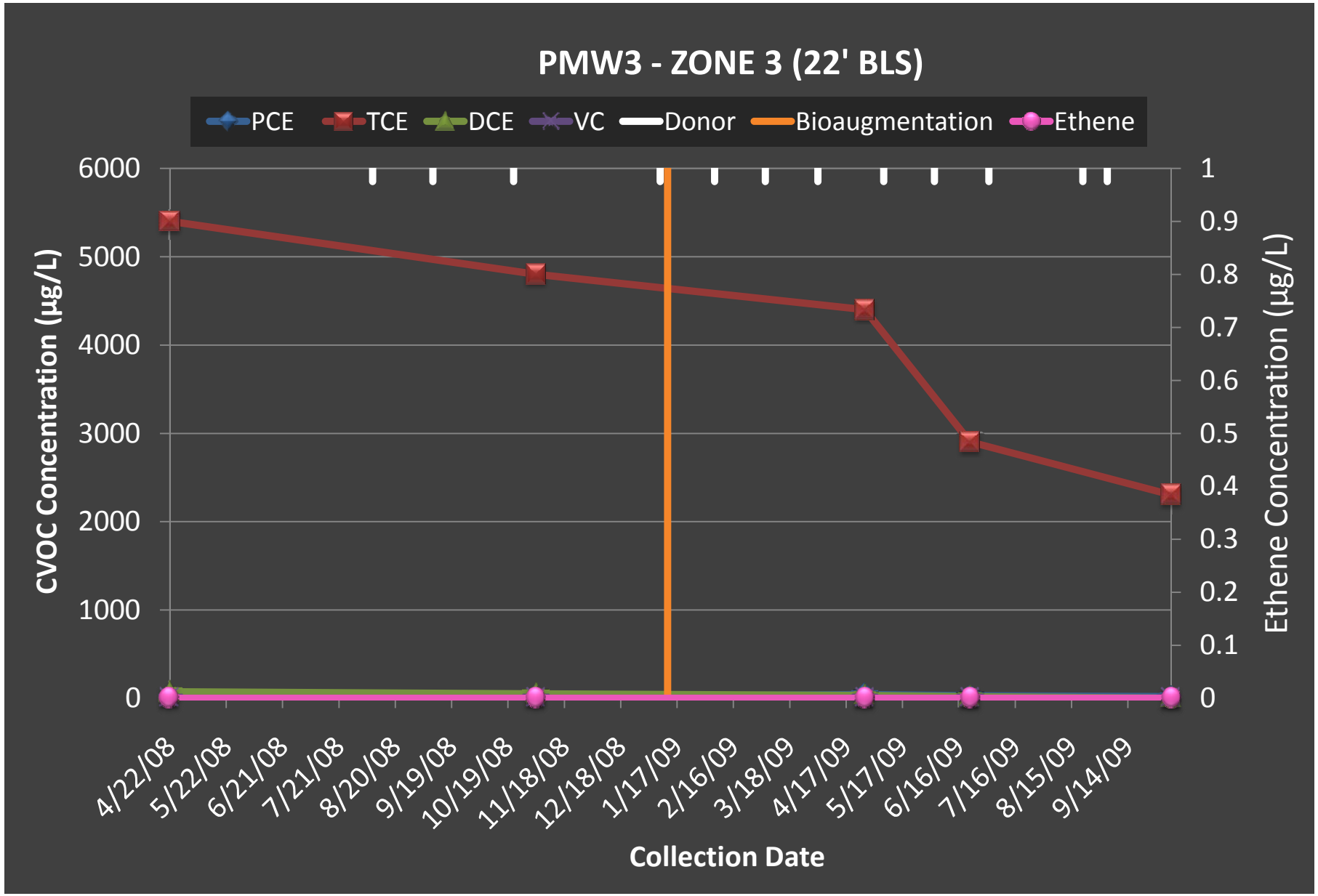

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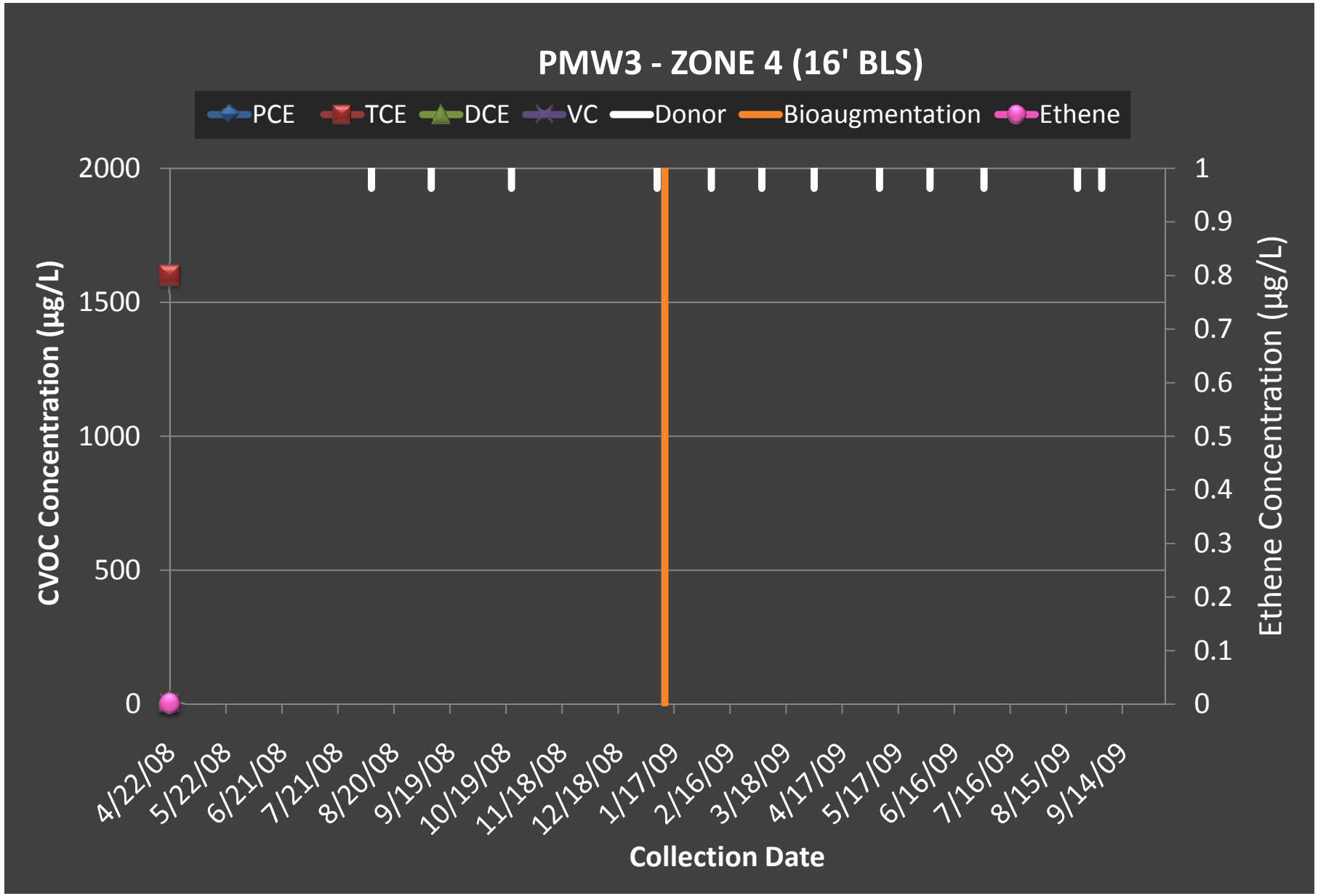

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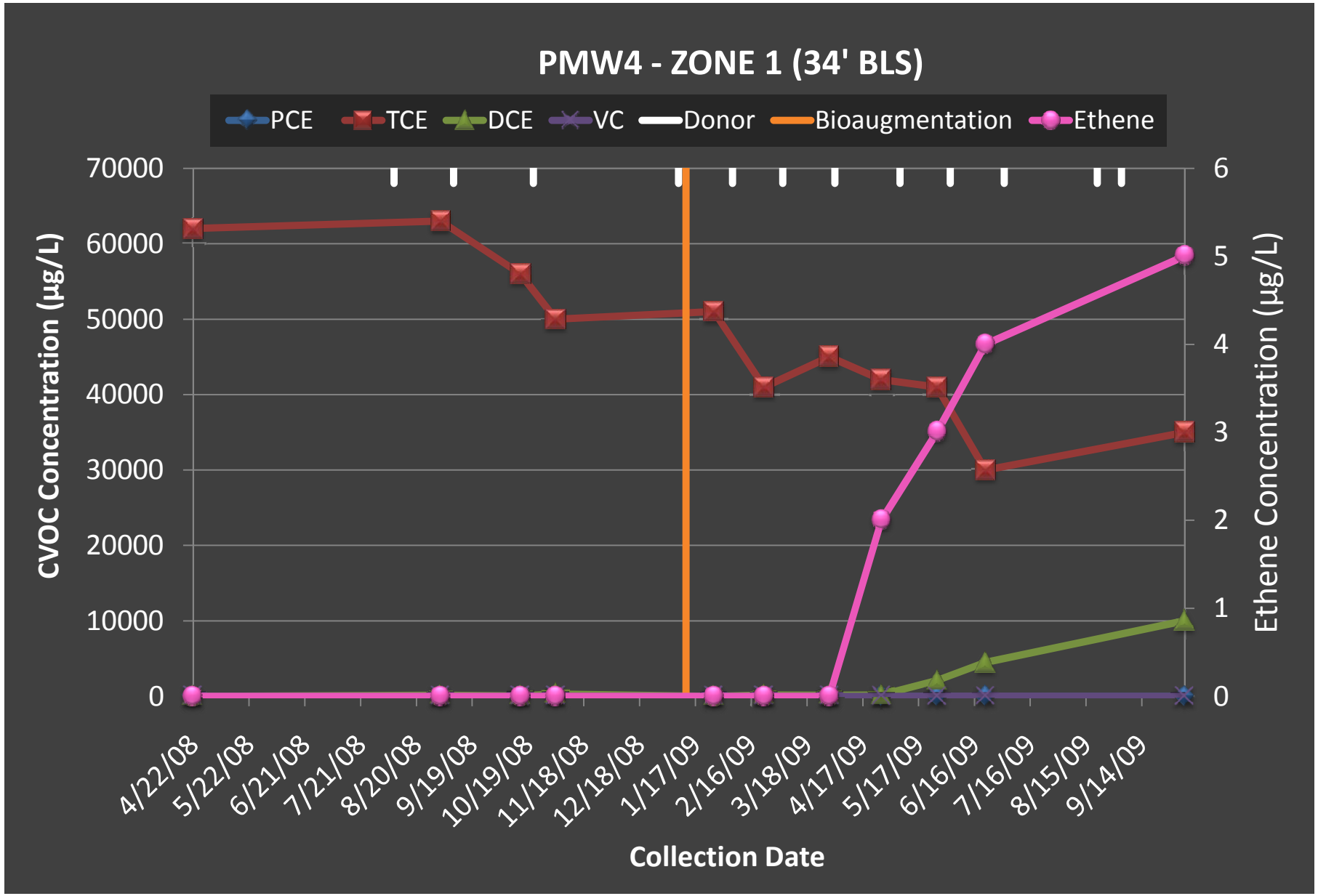

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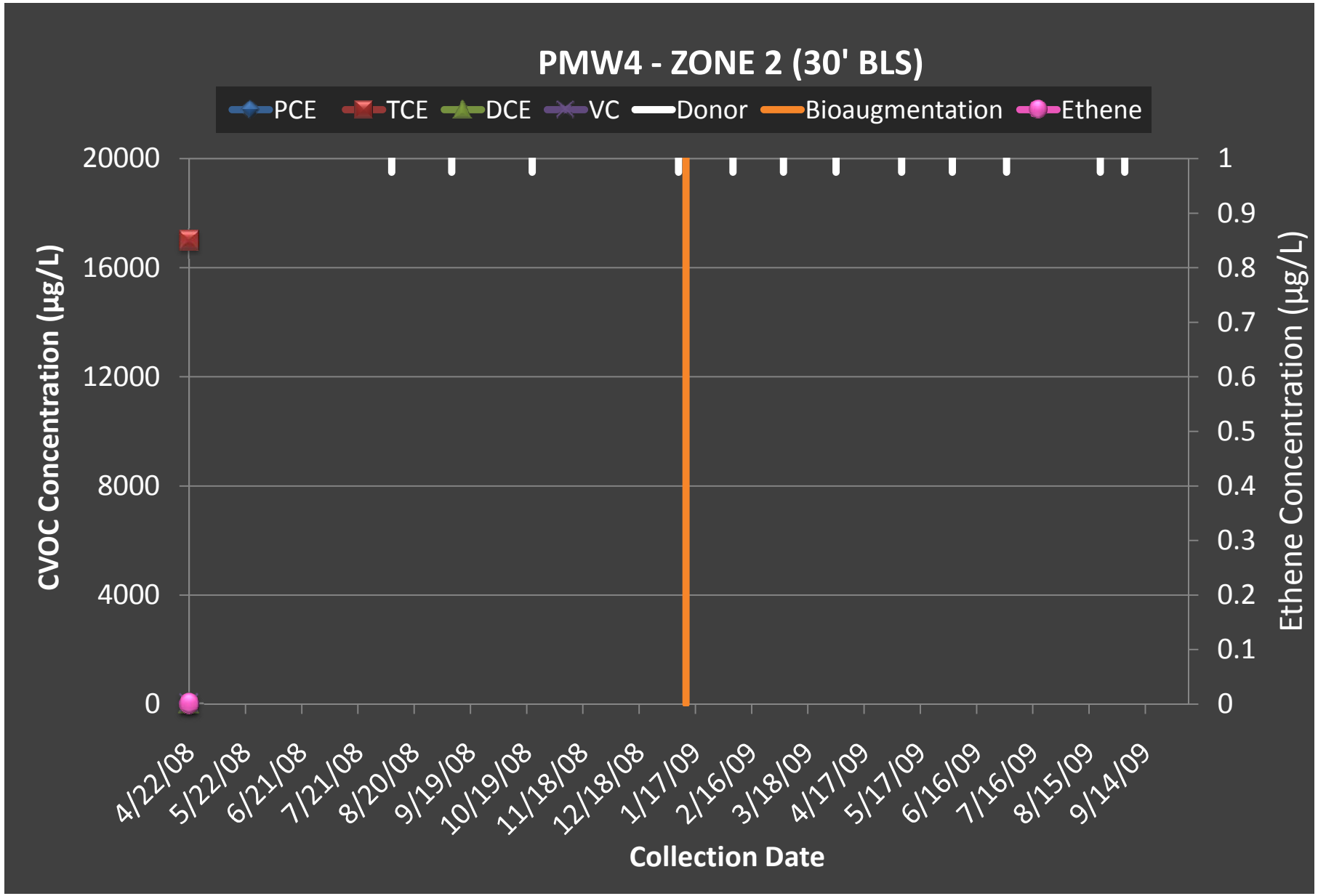

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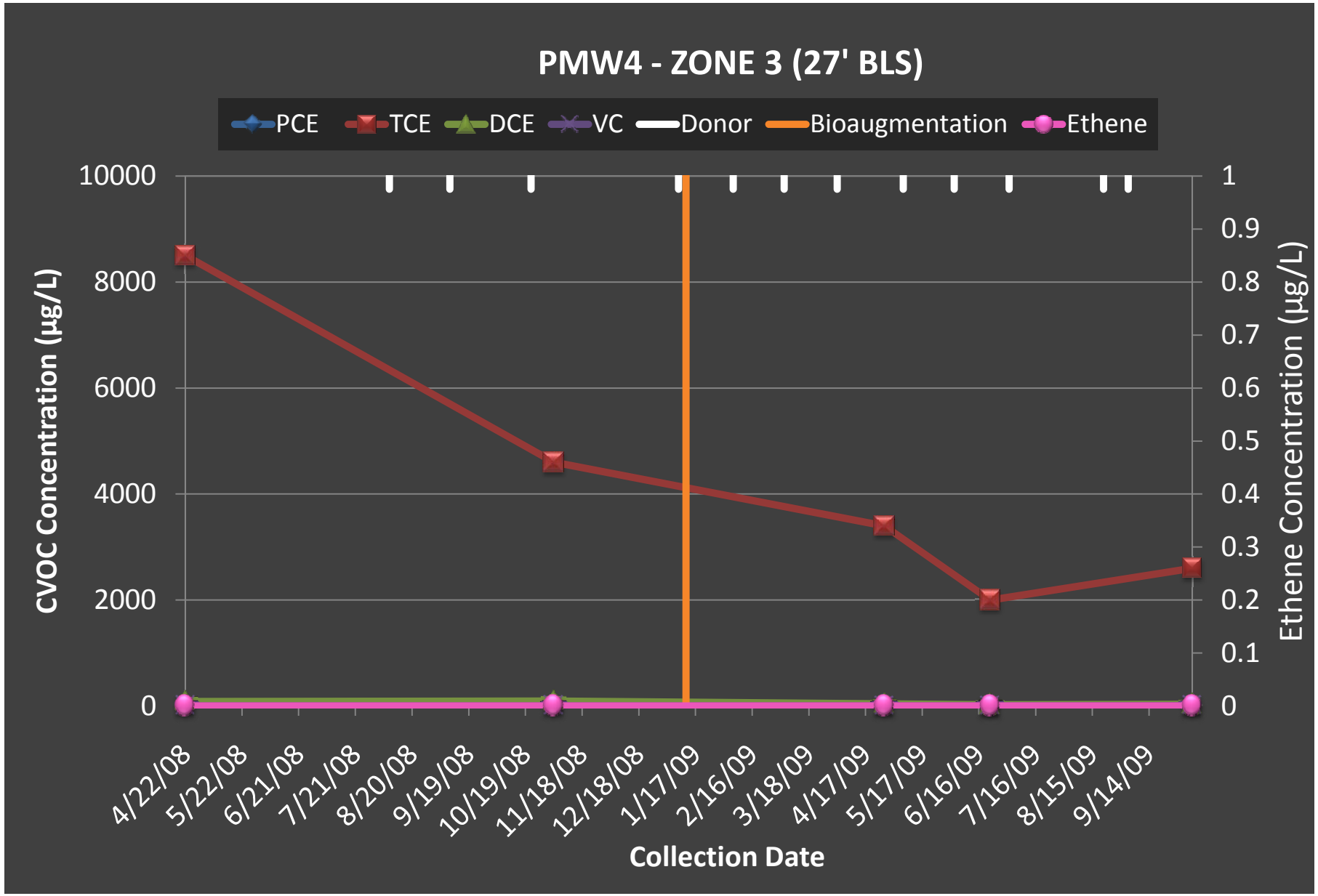

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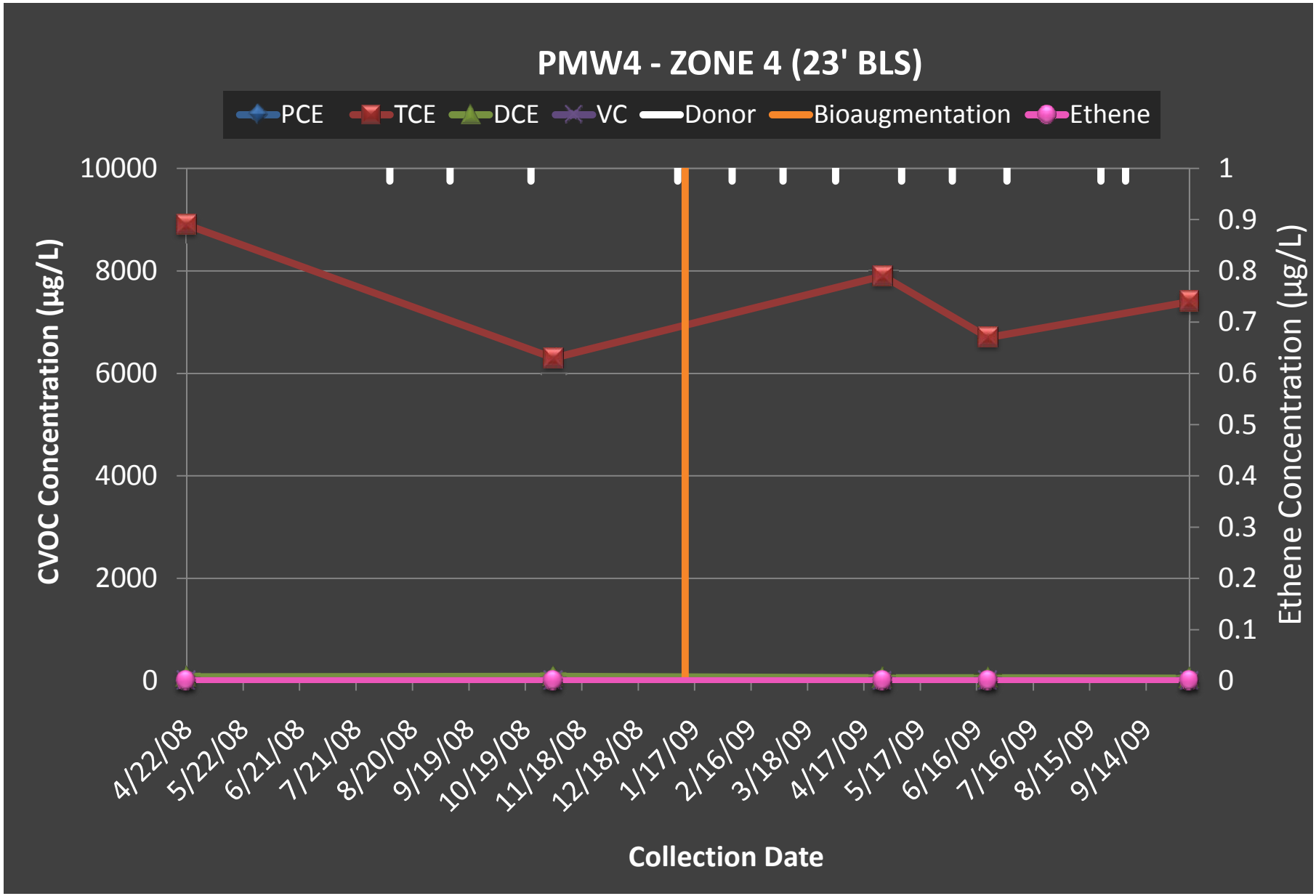

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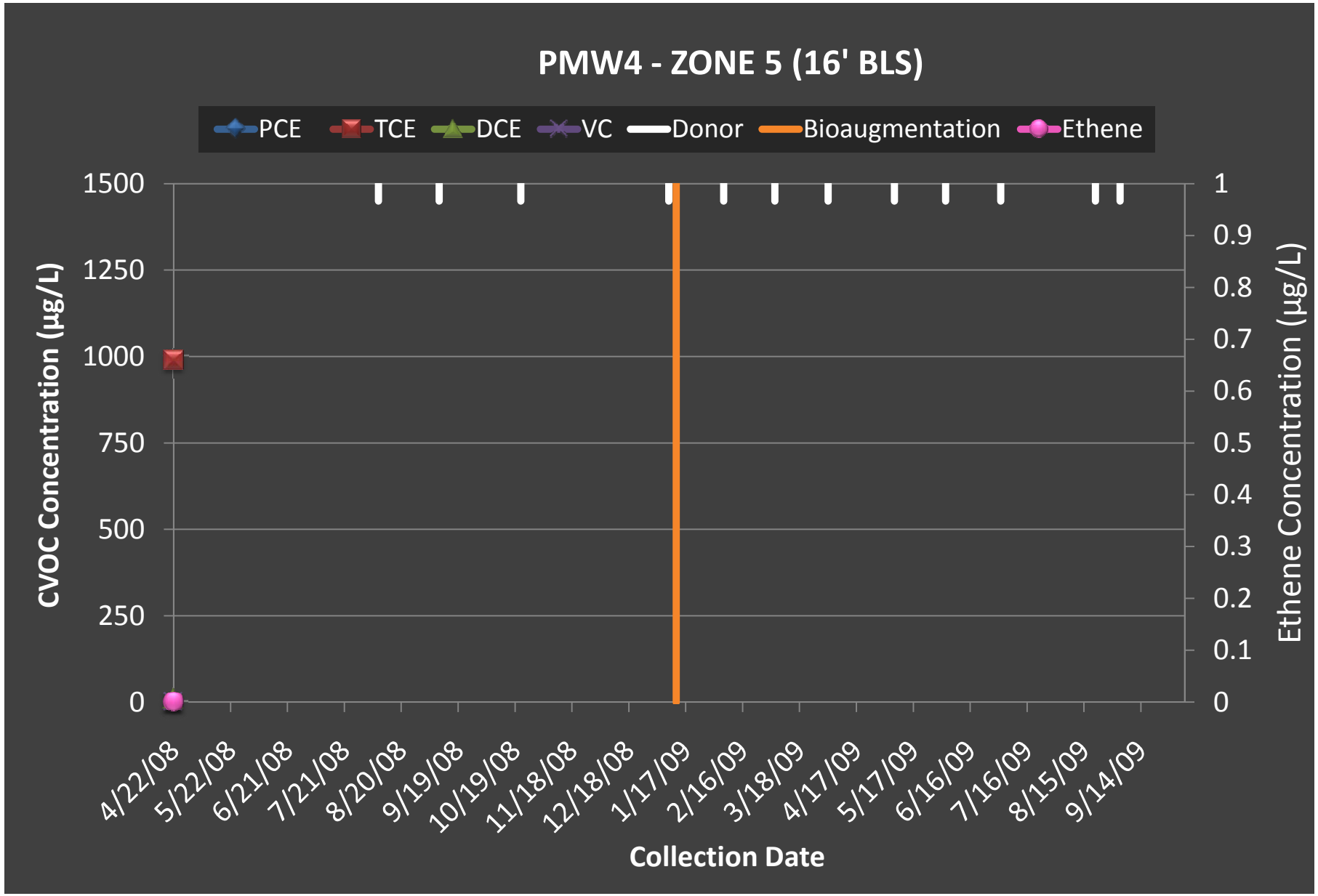

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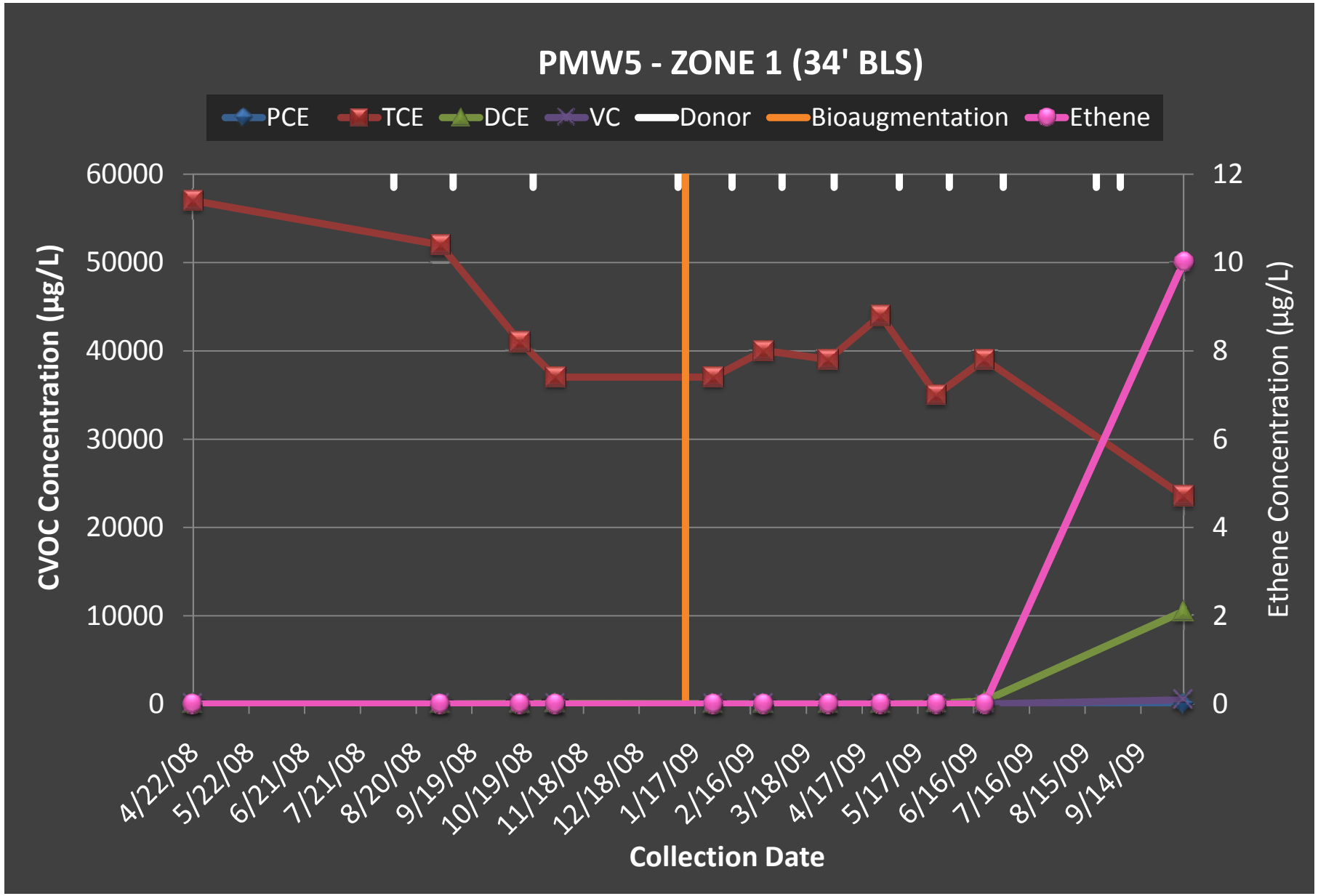

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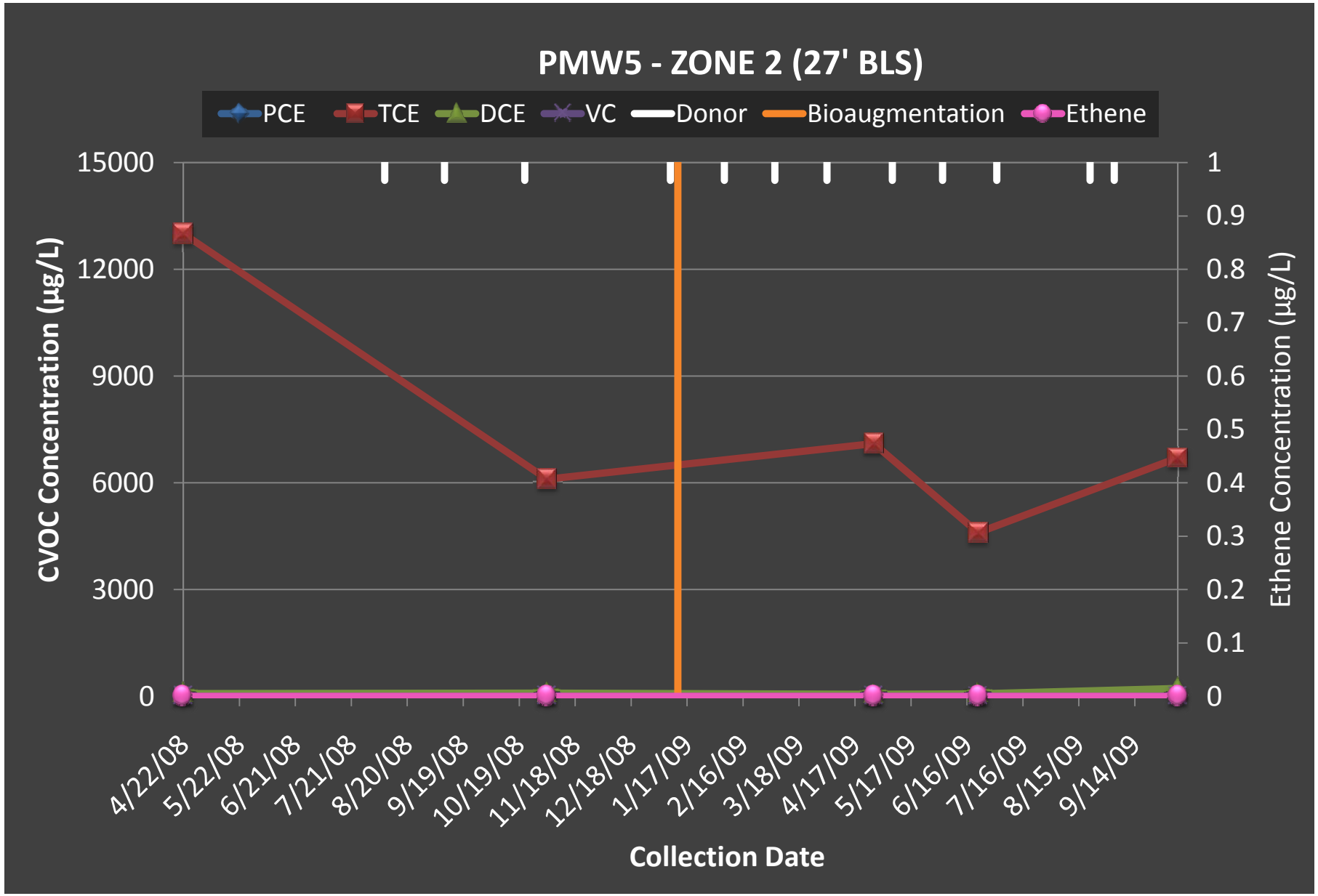

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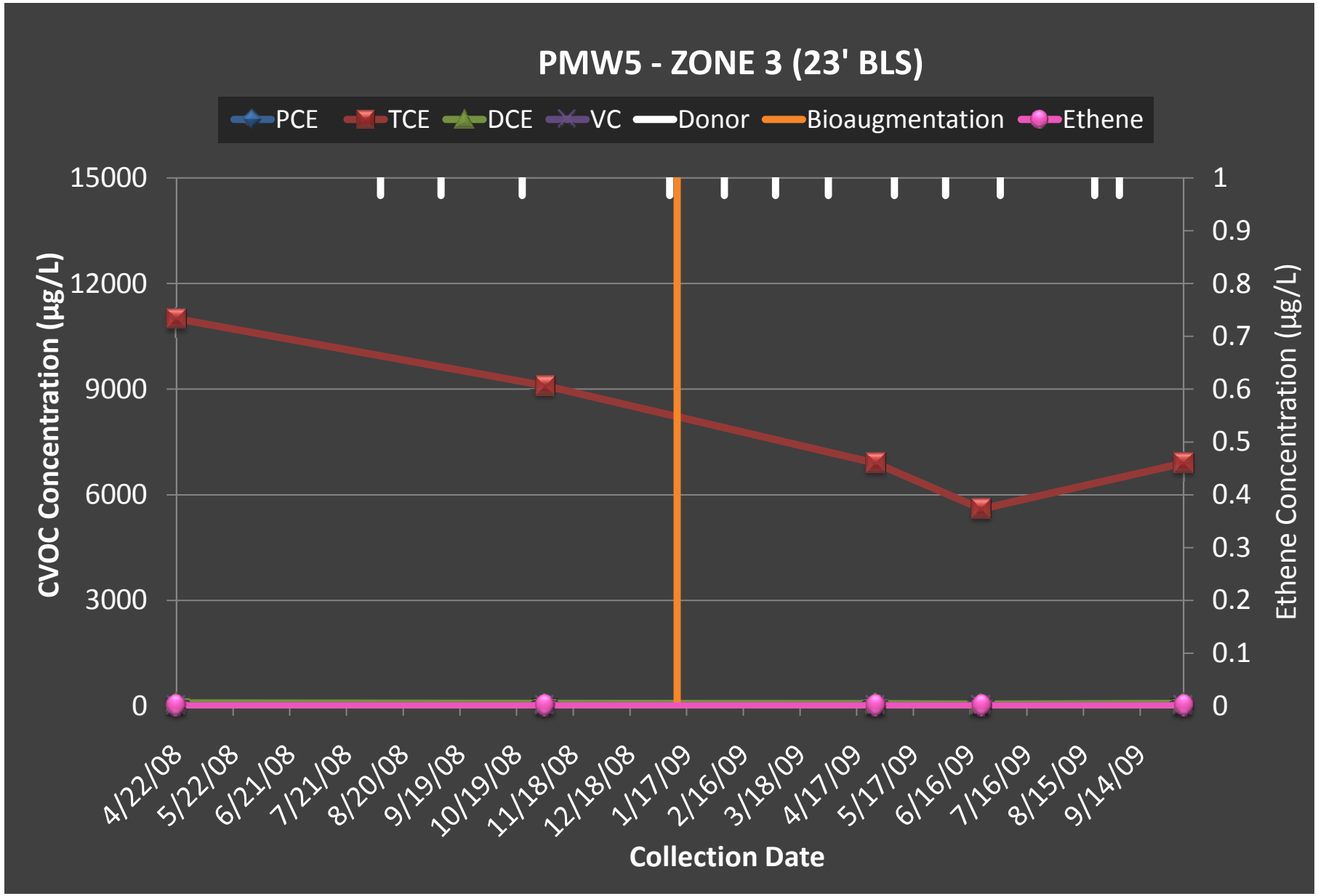

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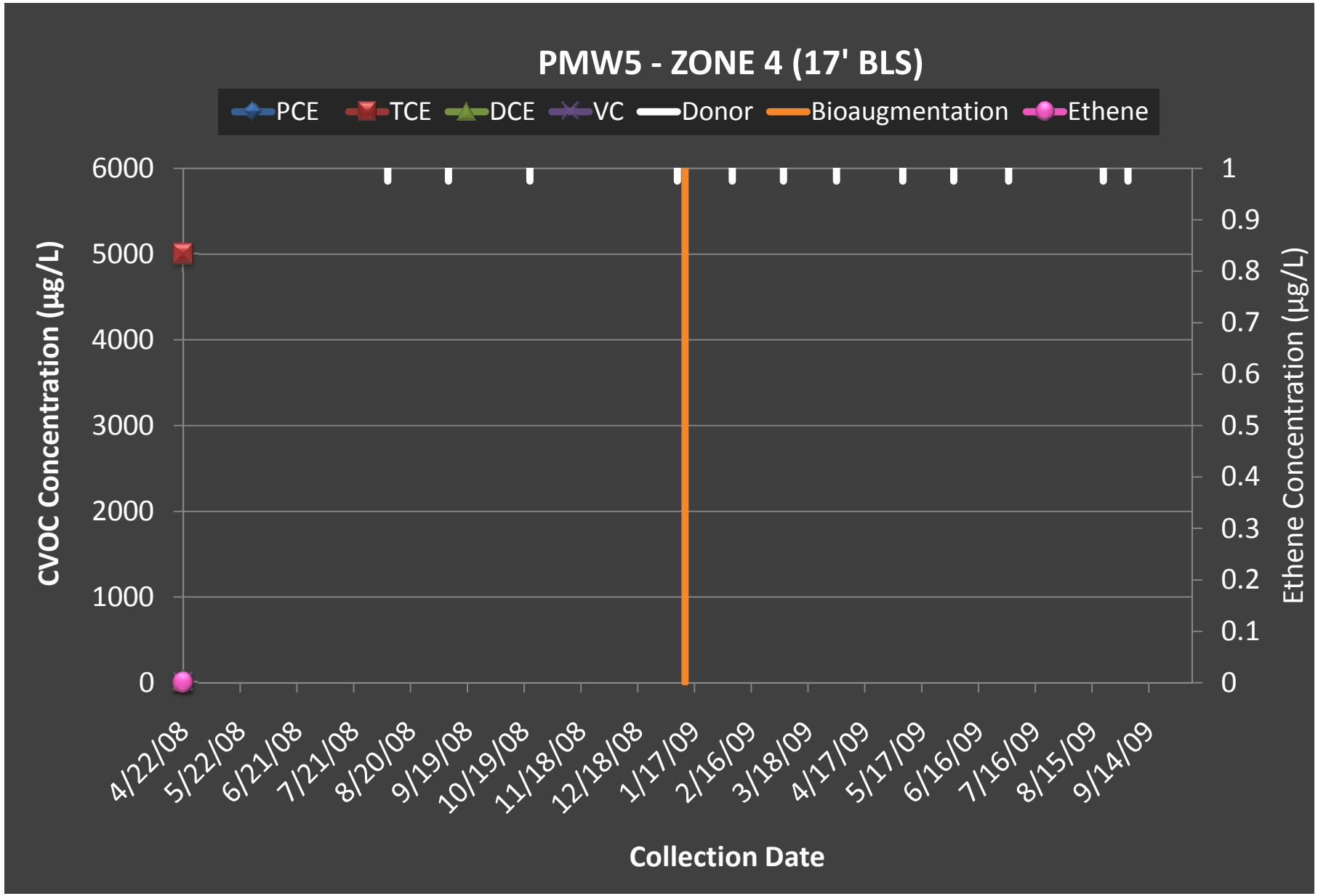

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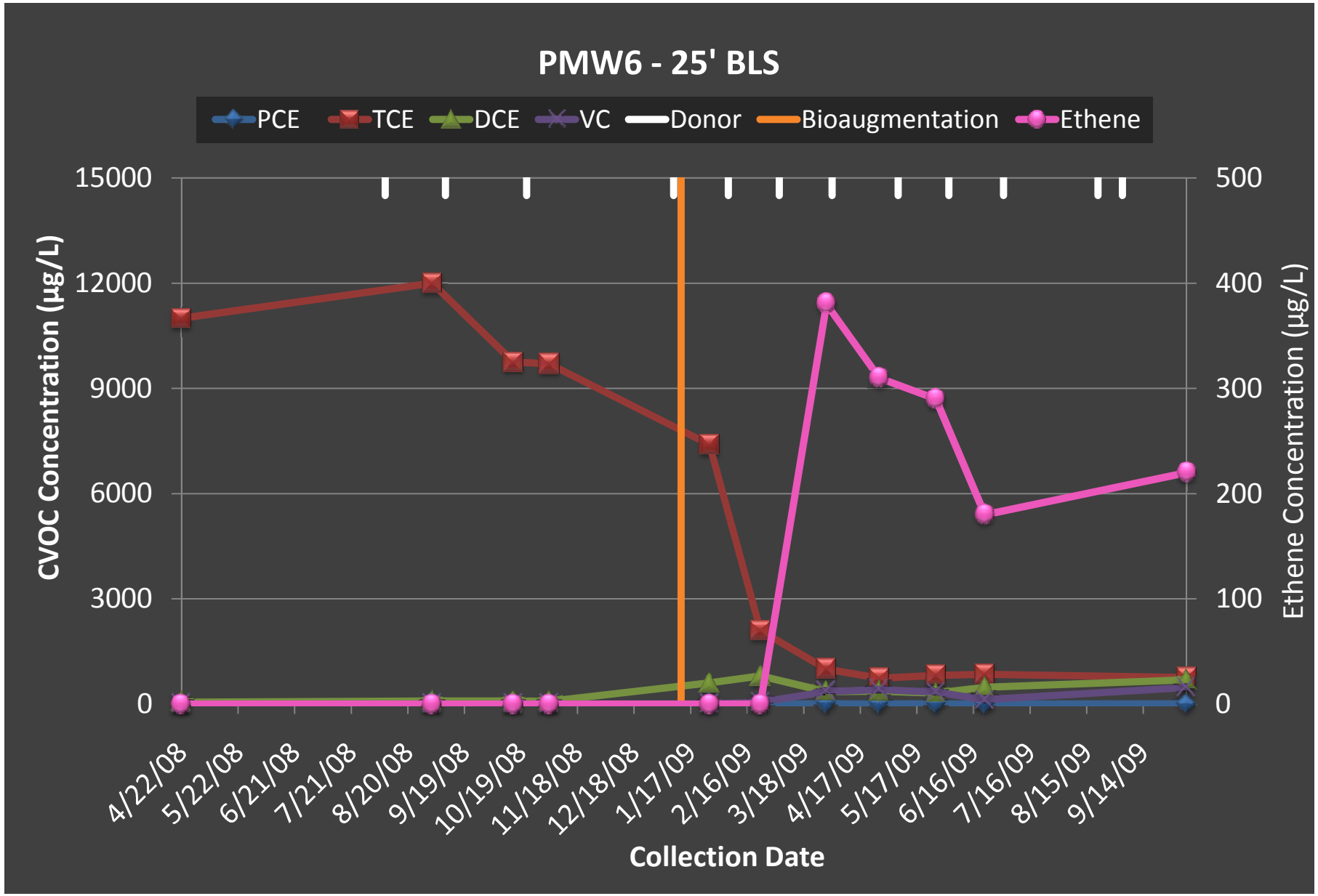

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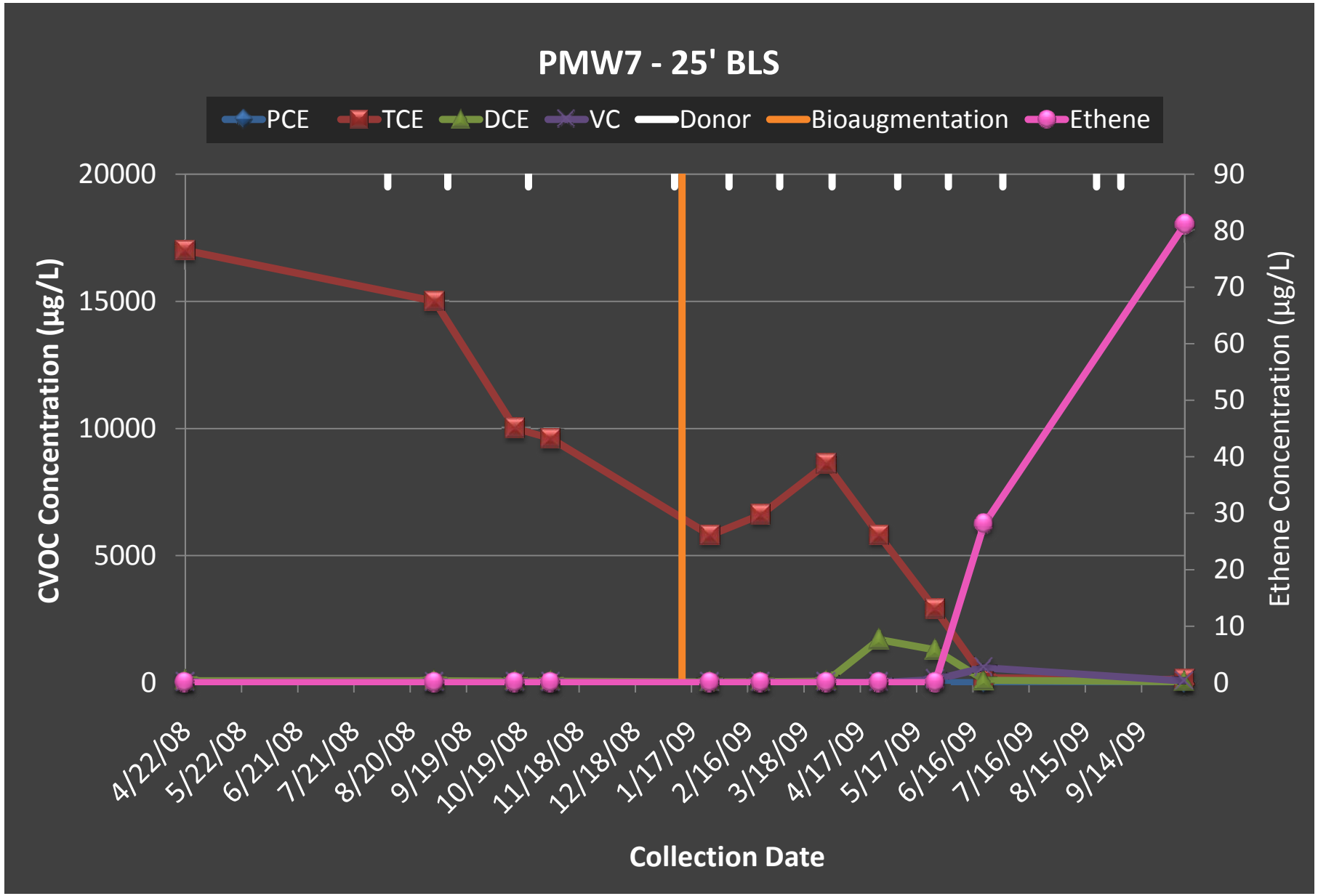

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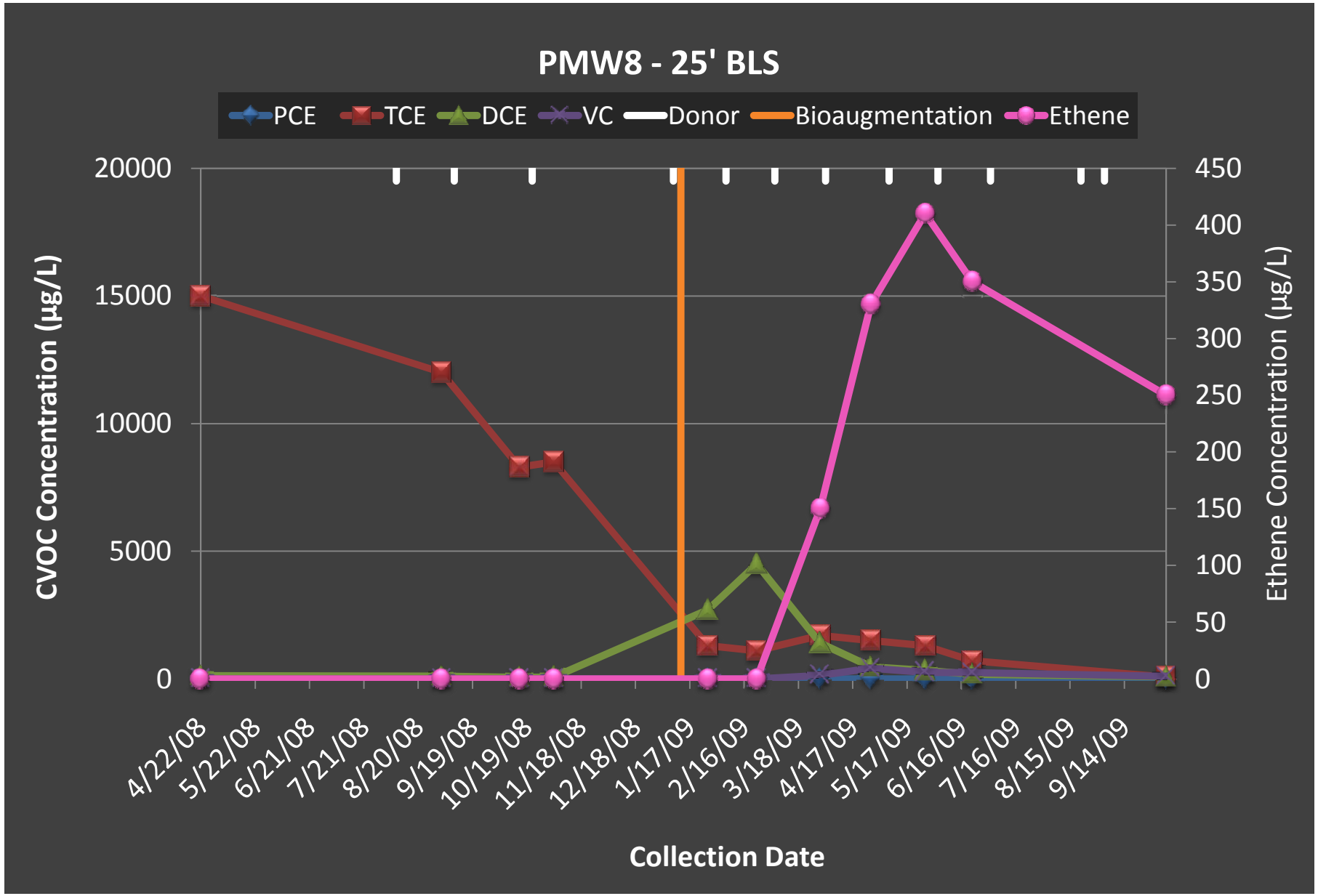

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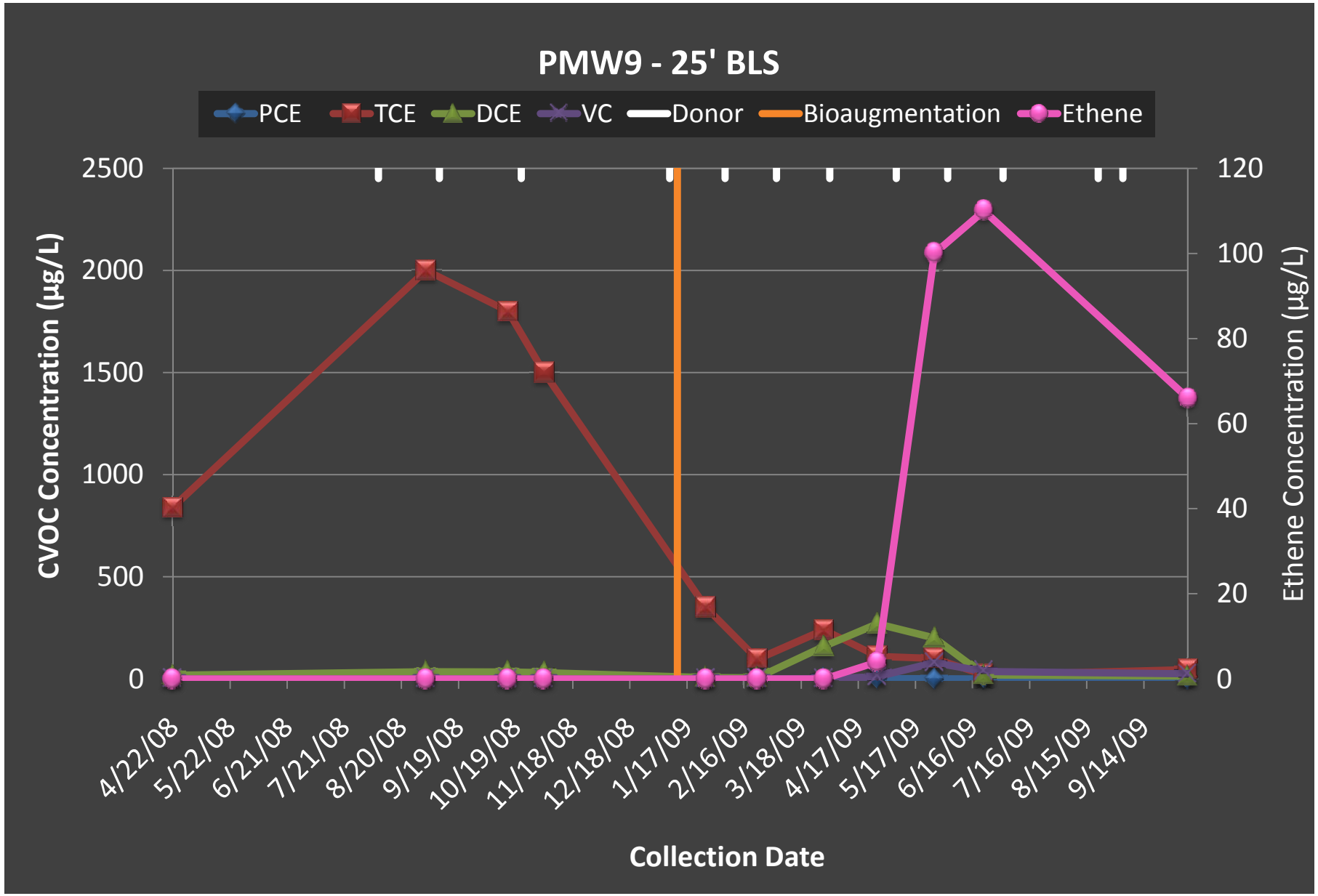

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Dechlorinating Bacteria

Seal Beach
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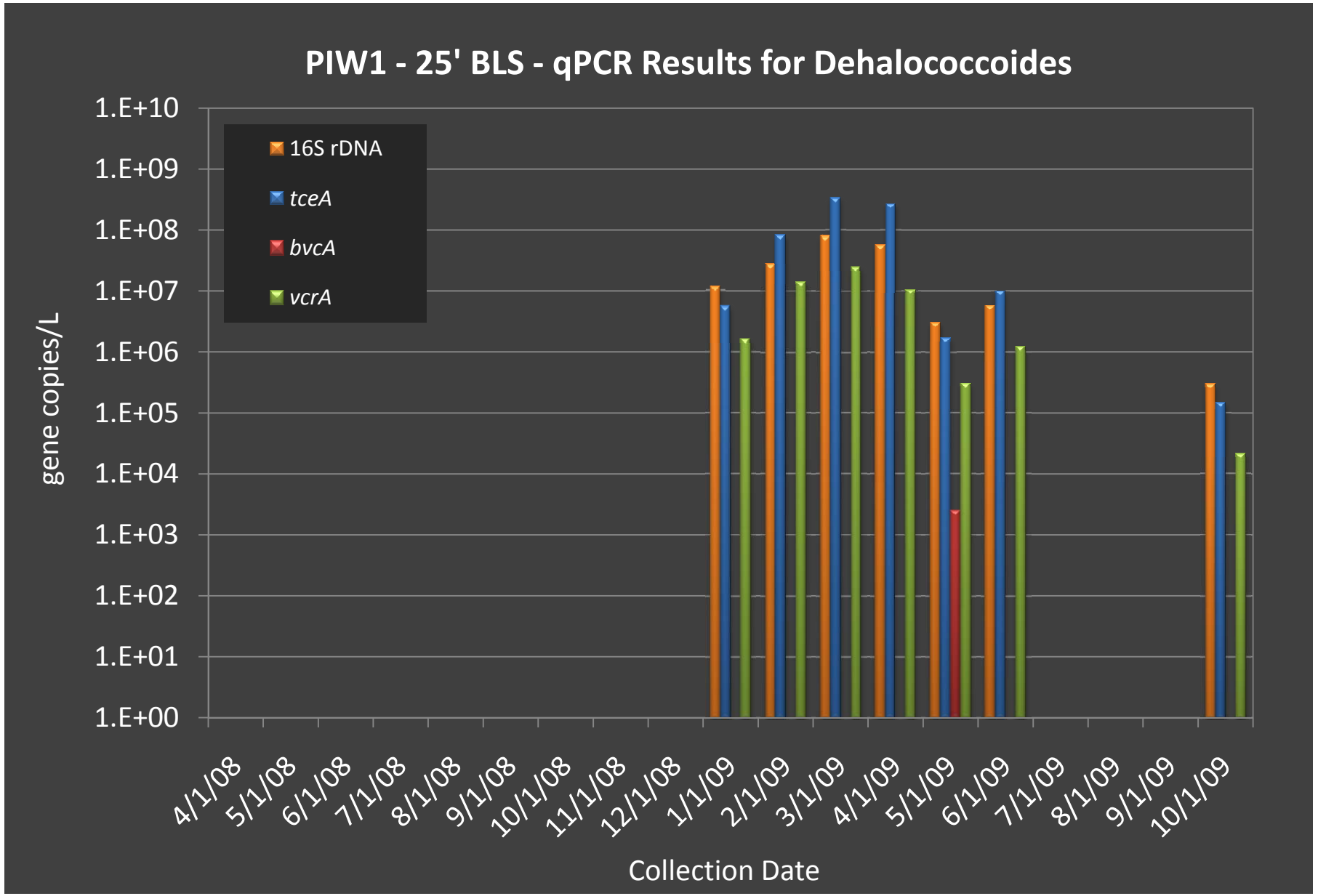

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Seal Beach
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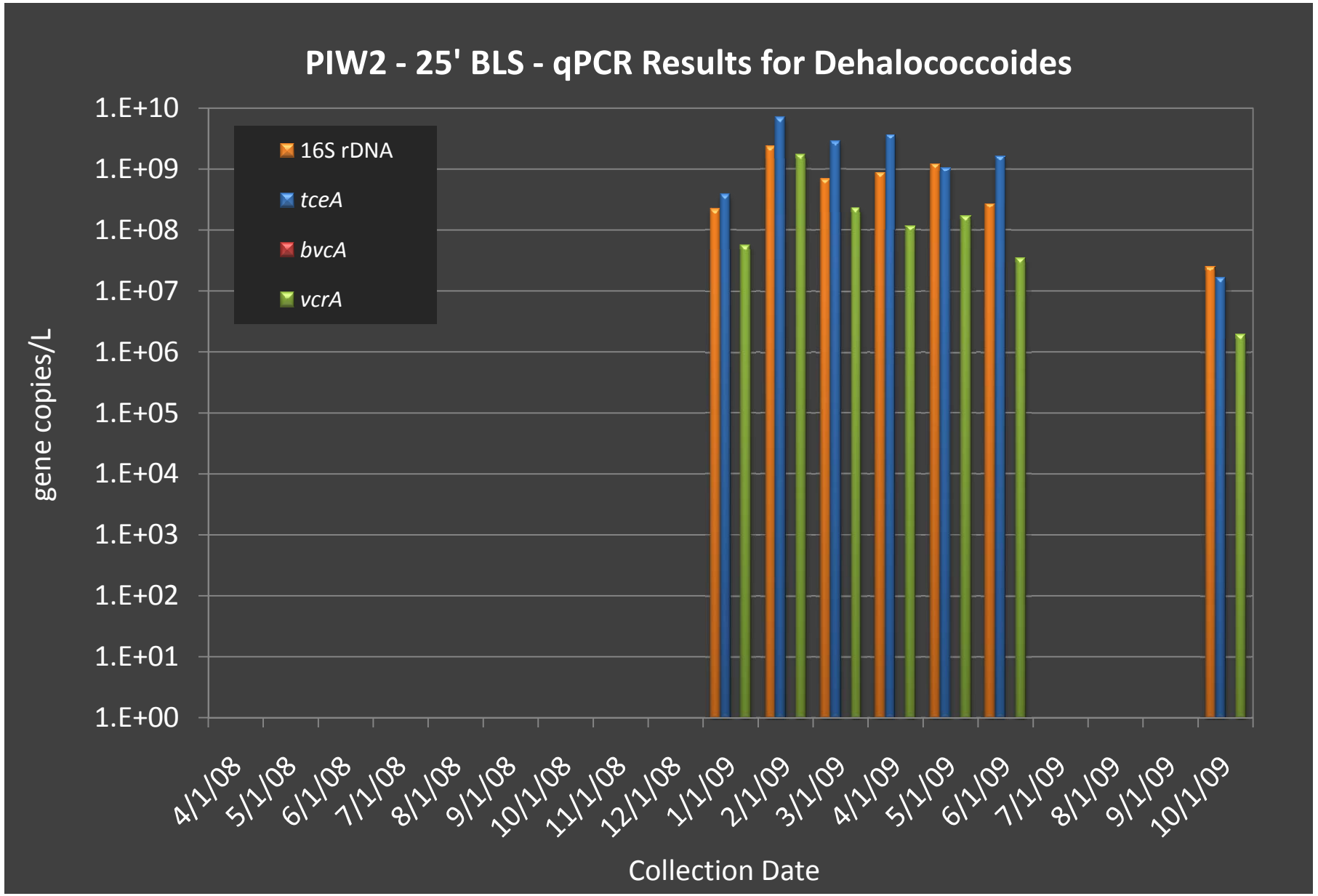

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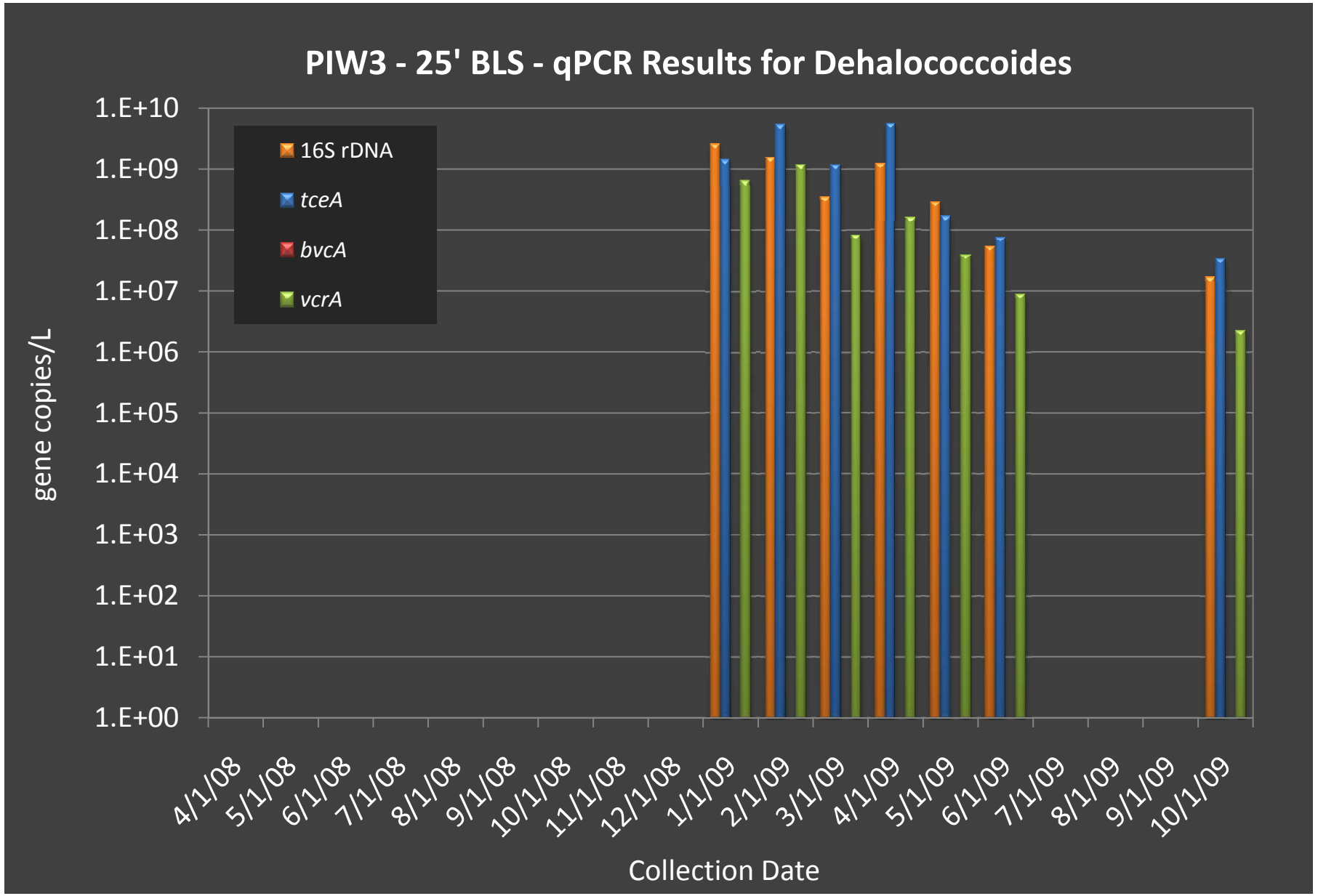

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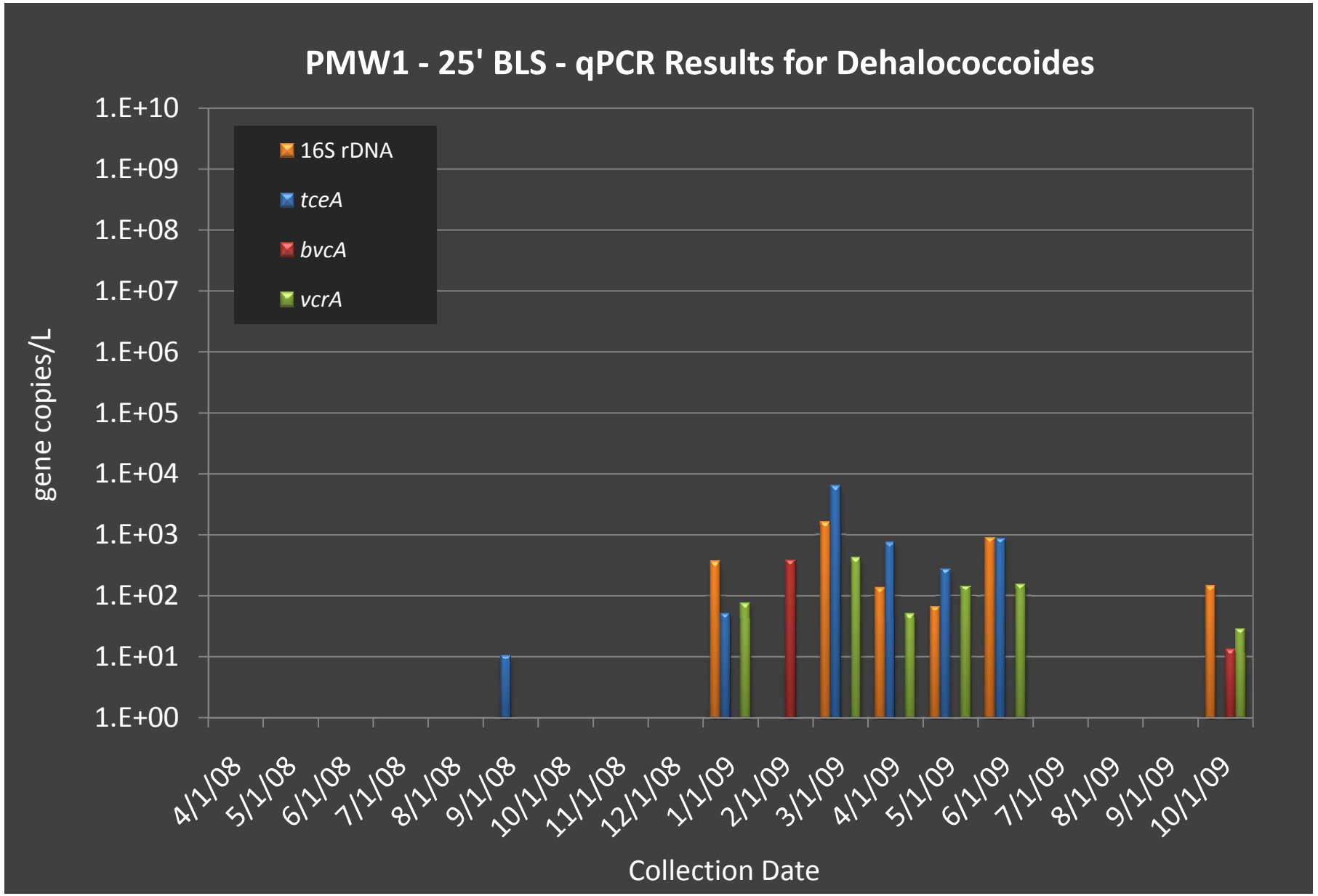

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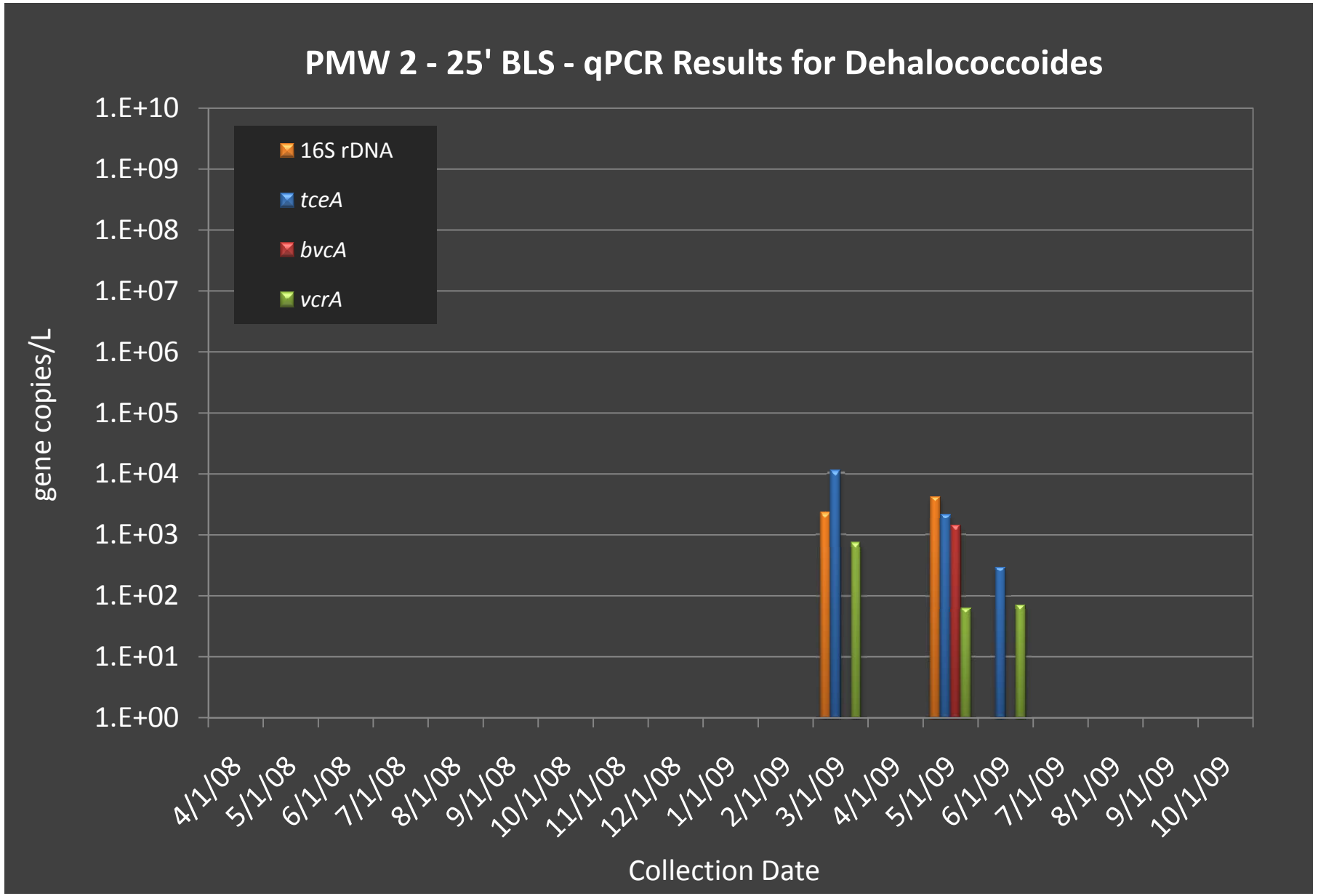

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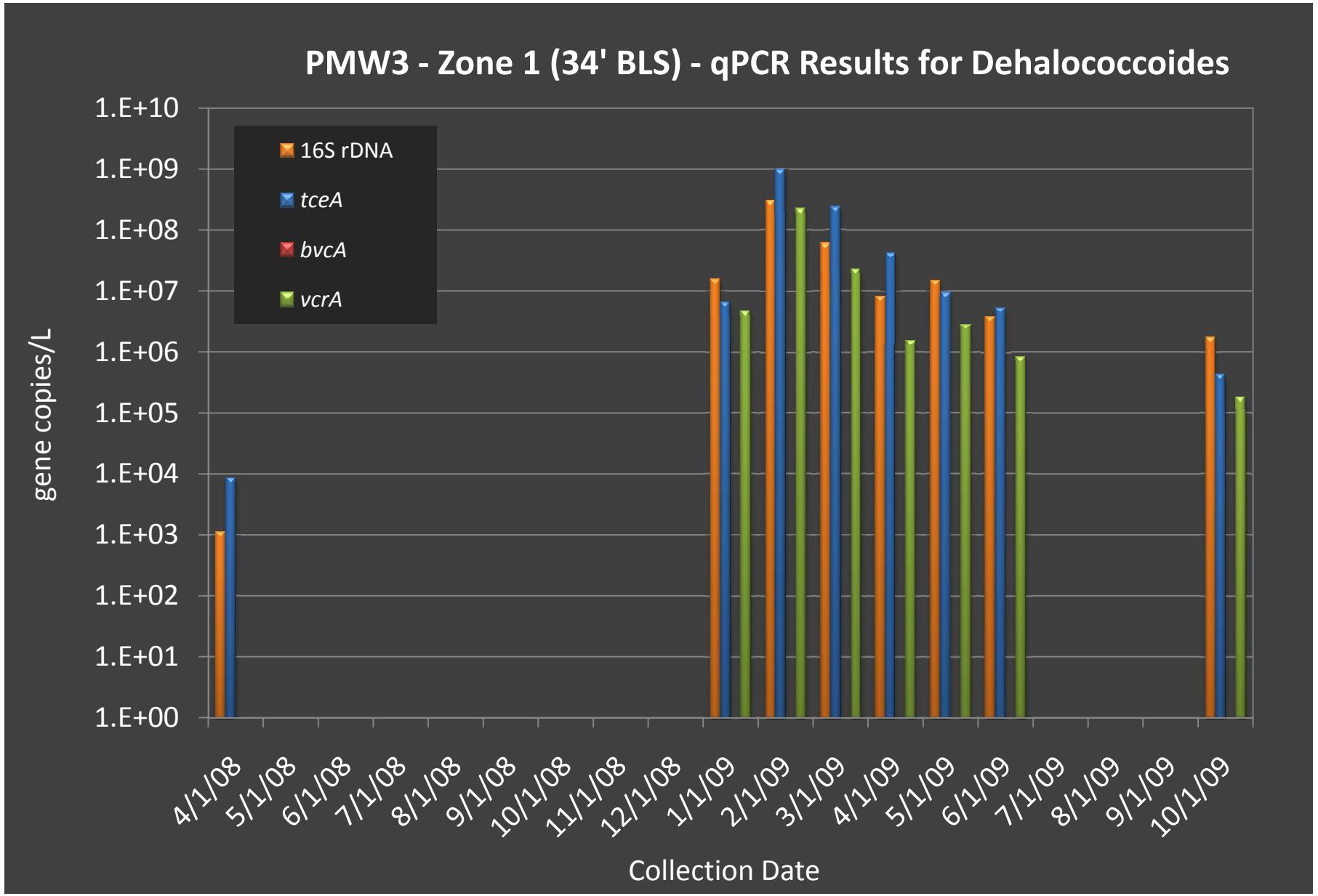

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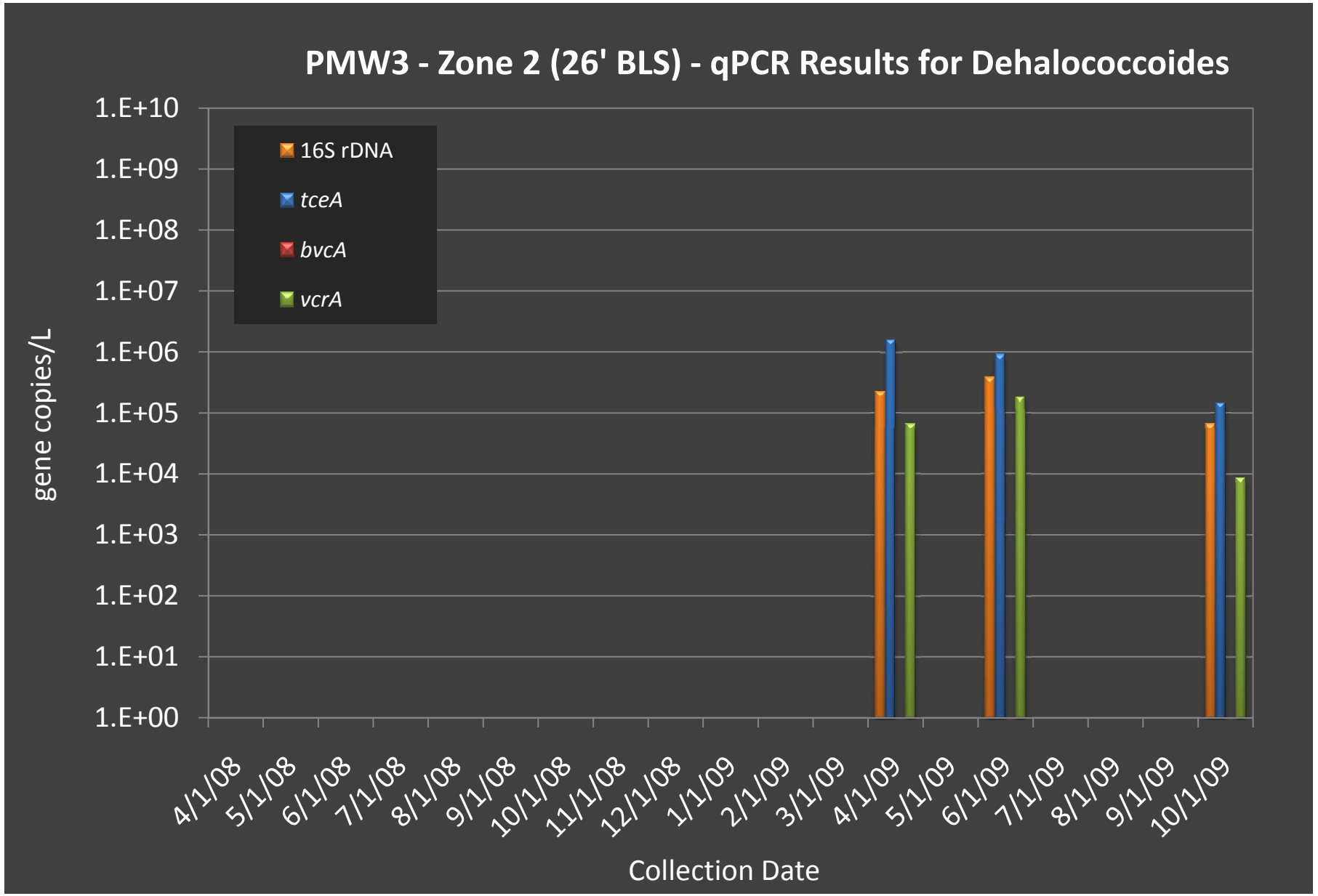

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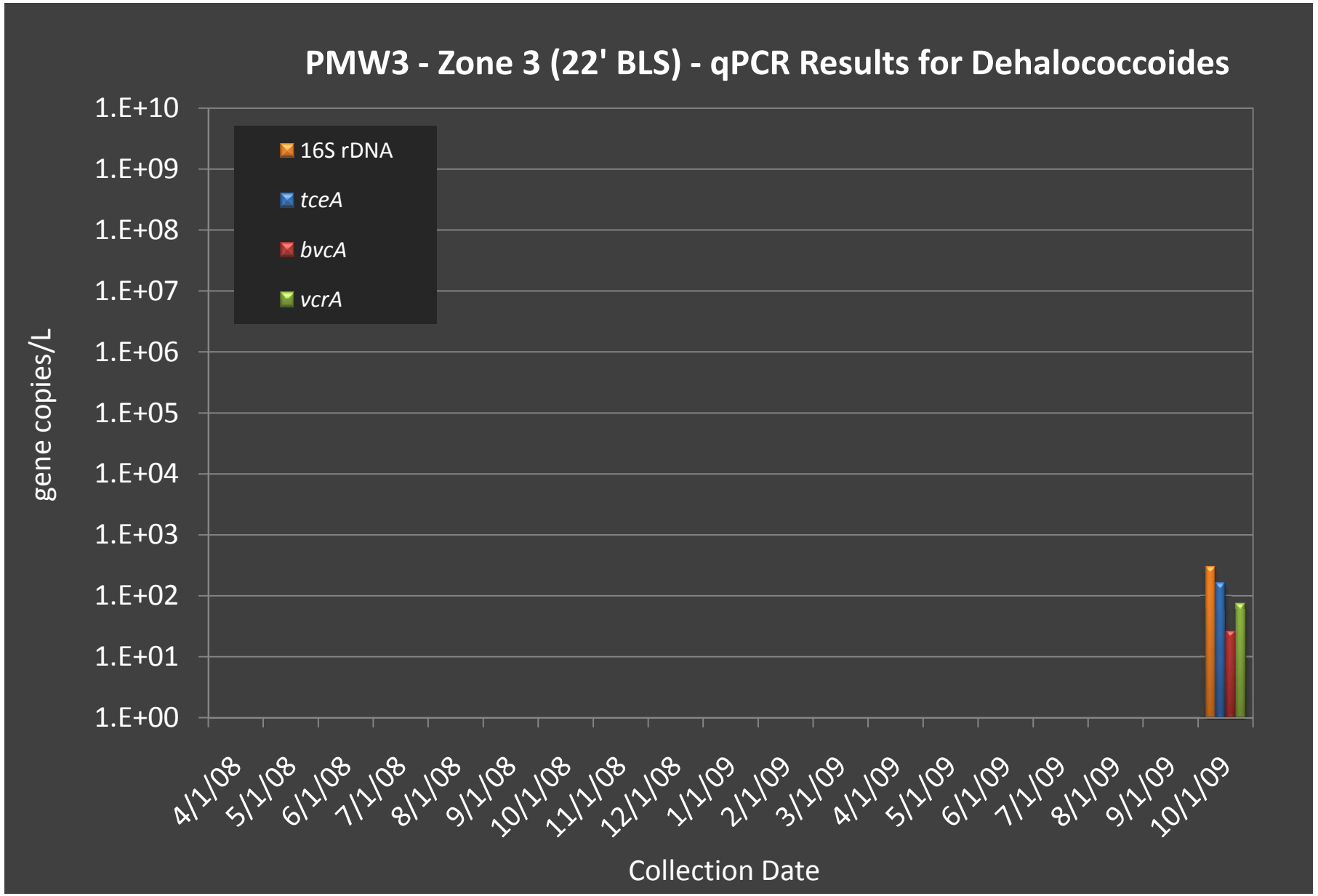
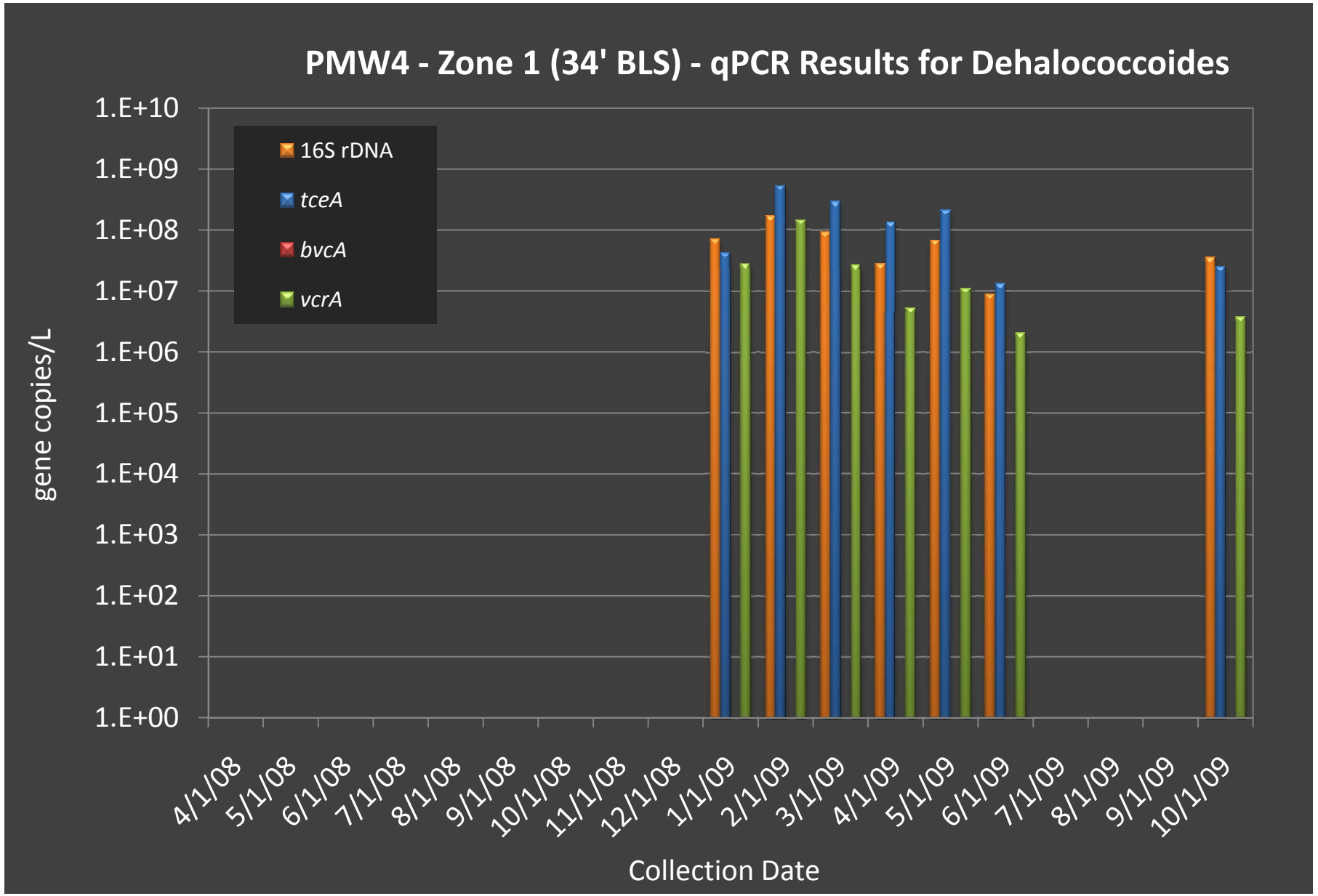
Seal Beach
Groundwater Bioaugmentation

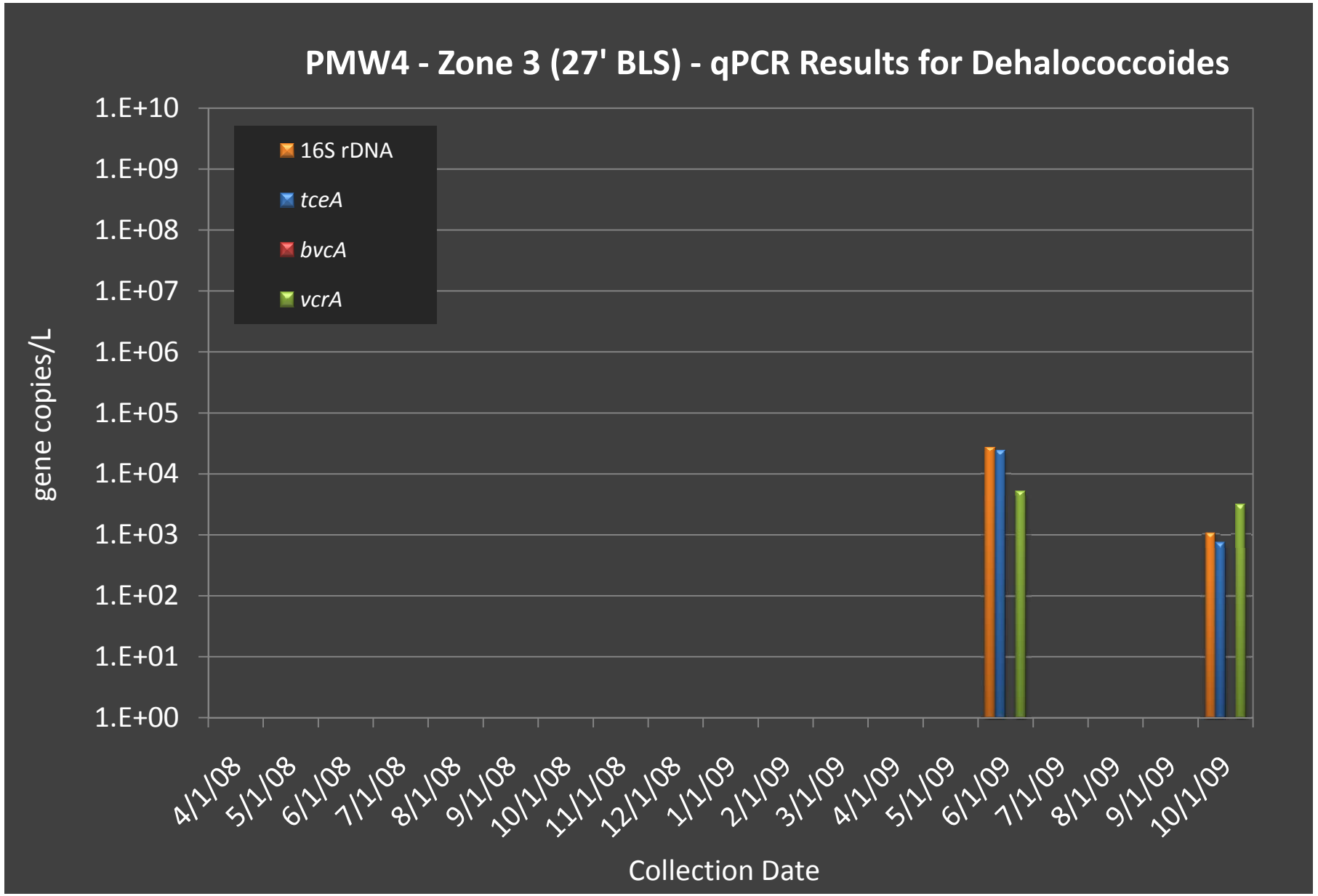


Seal Beach
Groundwater Bioaugmentation

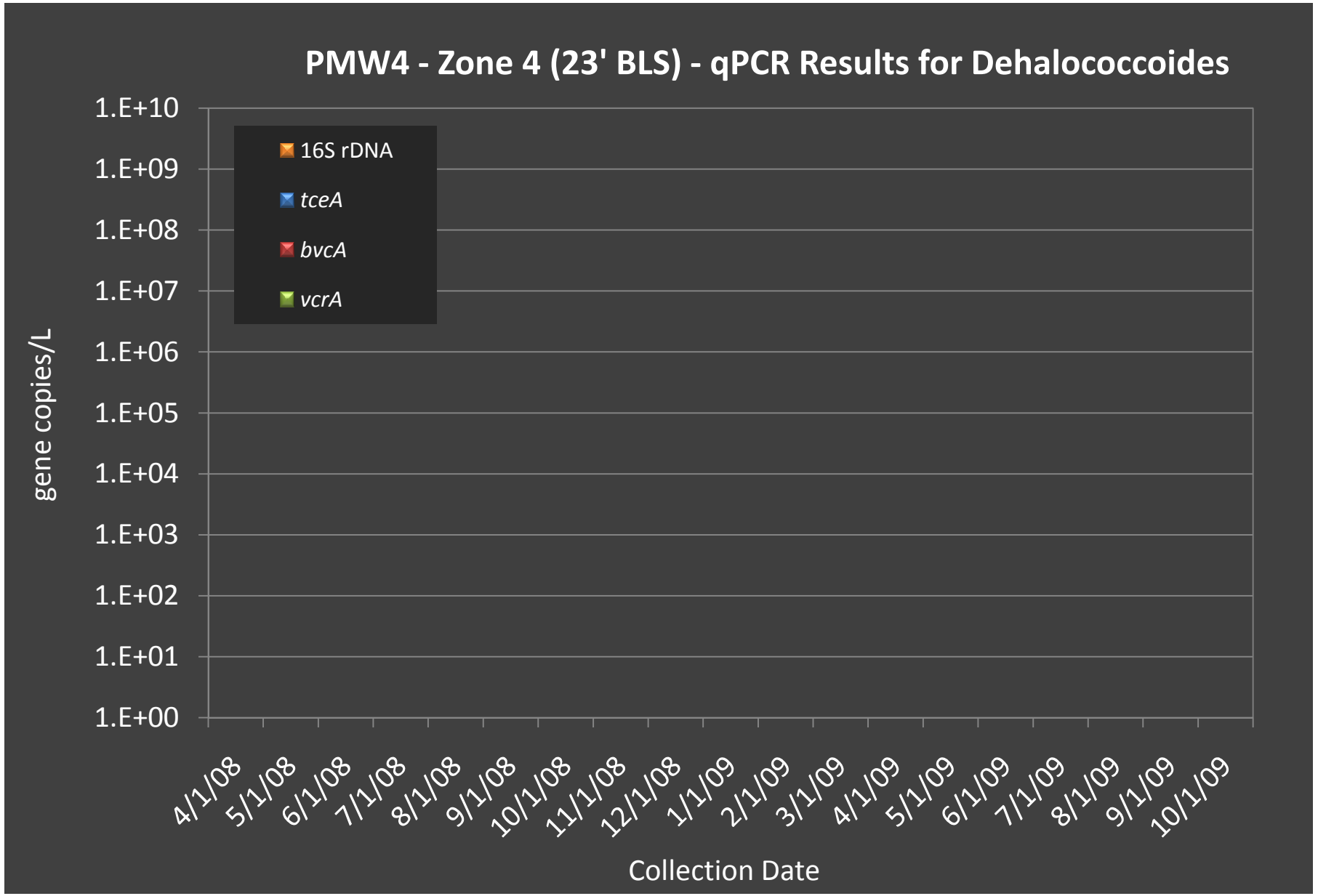


PMW4-Z1, DHC_Pas_Seal Beach_Oct 2009.xls

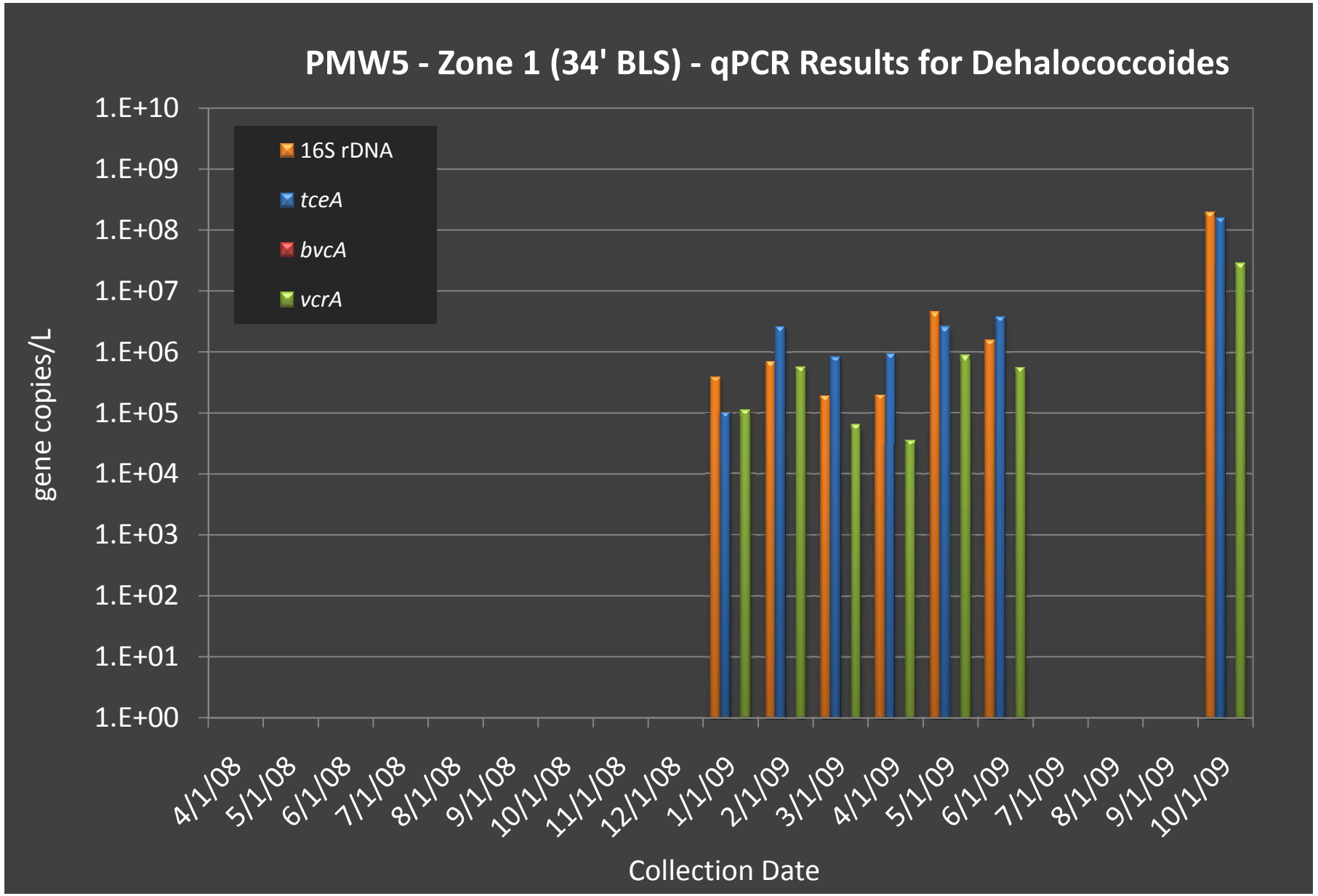
Seal Beach
Groundwater Bioaugmentation



PMW4-Z3, DHC_Pas_Seal Beach_Oct 2009.xls

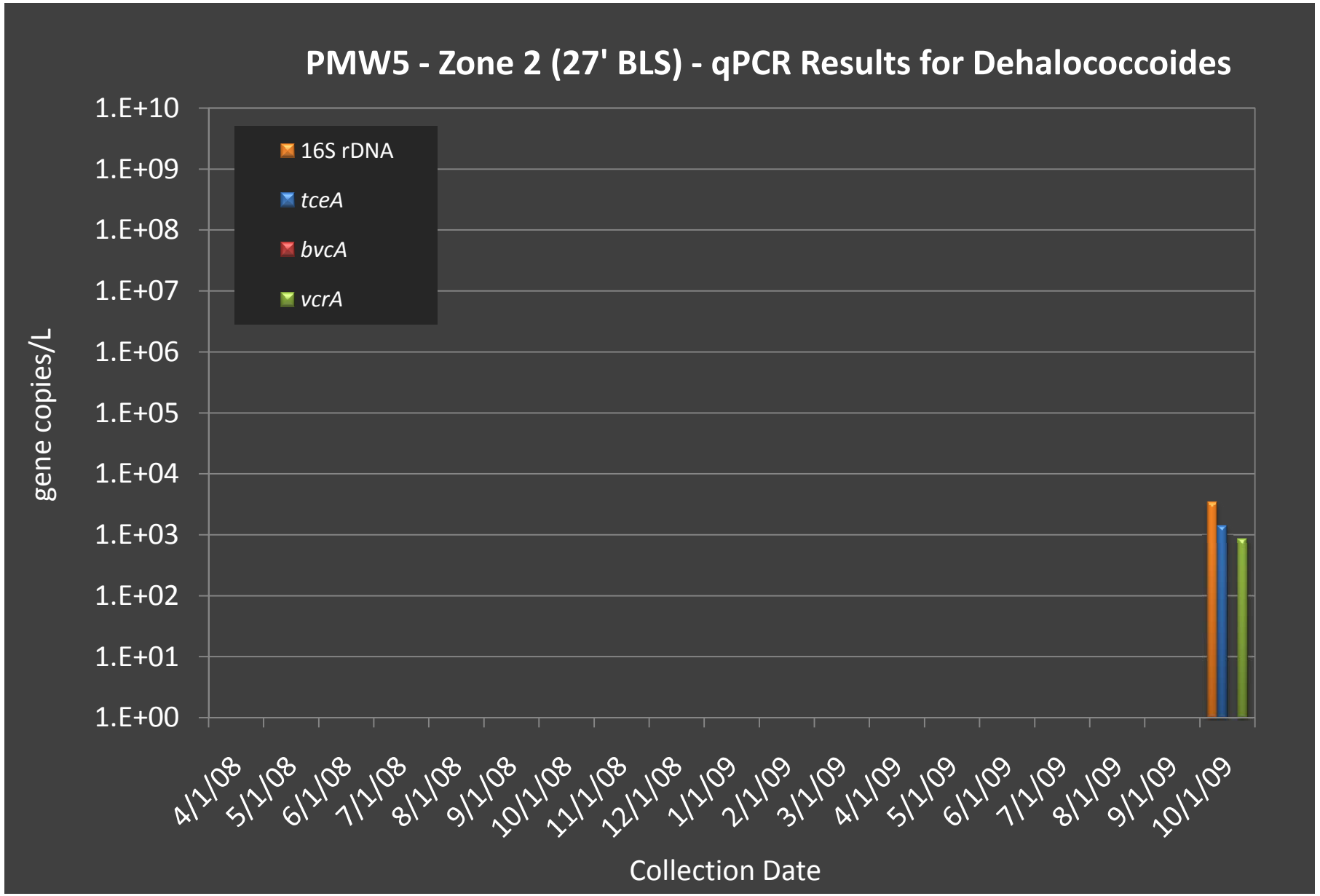

PMW4 - Zone 4 (23' BLS) - qPCR Results for Dehalococcoides
16S rDNA
tceA
bvcA
vcrA
gene copies/L
1.E+10
1.E+09
1.E+08
1.E+07
1.E+06
1.E+05
1.E+04
1.E+03
1.E+02
1.E+01
1.E+00
4/1/08
5/1/08
6/1/08
7/1/08
8/1/08
9/1/08
10/1/08
11/1/08
12/1/08
1/1/09
2/1/09
3/1/09
4/1/09
5/1/09
6/1/09
7/1/09
8/1/09
9/1/09
10/1/09
Collection Date

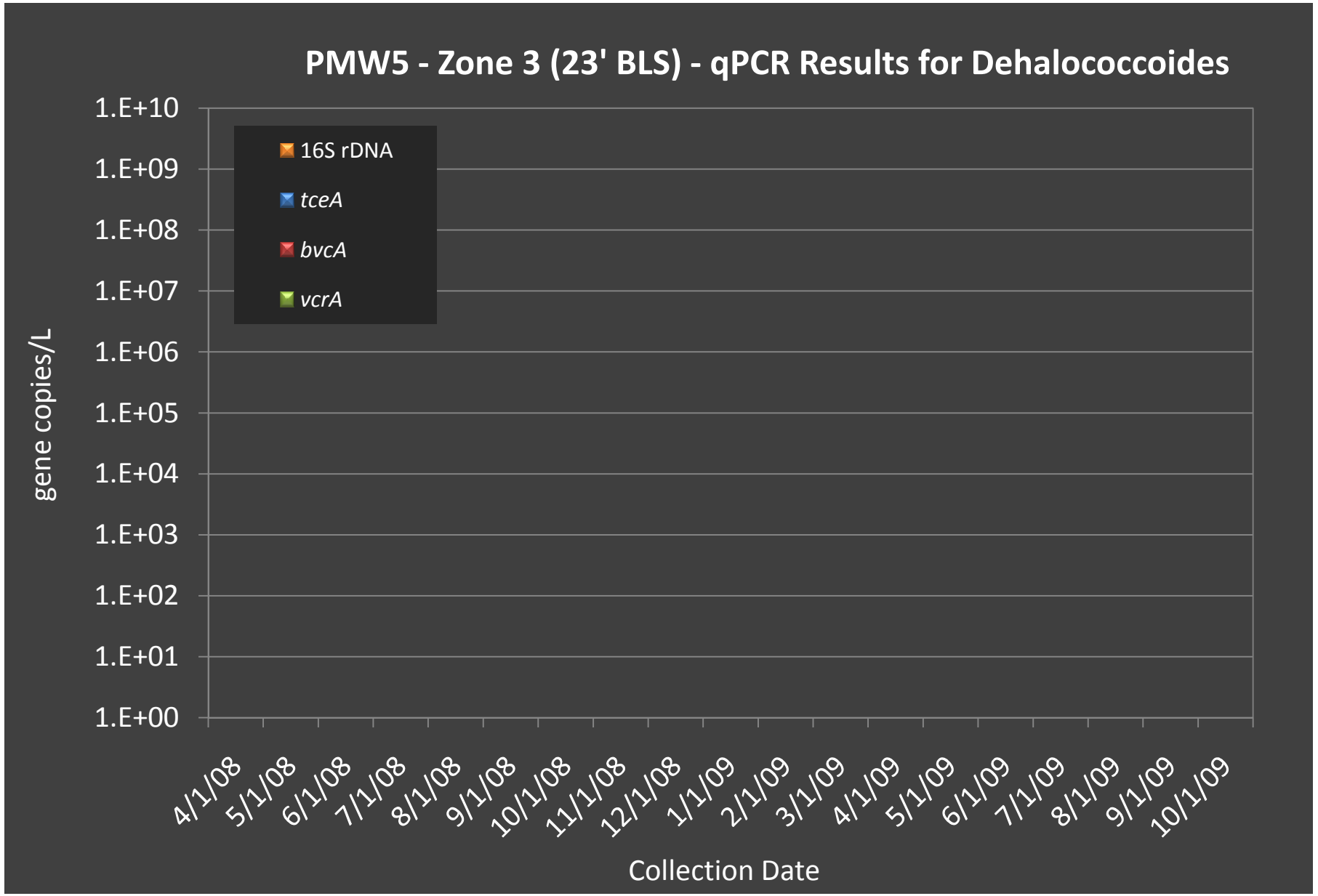
Seal Beach
Groundwater Bioaugmentation



PMW5-Z1, DHC_Pas_Seal Beach_Oct 2009.xls

Seal Beach
Groundwater Bioaugmentation




PMW5 - Zone 3 (23' BLS) - qPCR Results for Dehalococcoides
16S rDNA
tceA
bvcA
vcrA
gene copies/L
1.E+10
1.E+09
1.E+08
1.E+07
1.E+06
1.E+05
1.E+04
1.E+03
1.E+02
1.E+01
1.E+00
4/1/08
5/1/08
6/1/08
7/1/08
8/1/08
9/1/08
10/1/08
11/1/08
12/1/08
1/1/09
2/1/09
3/1/09
4/1/09
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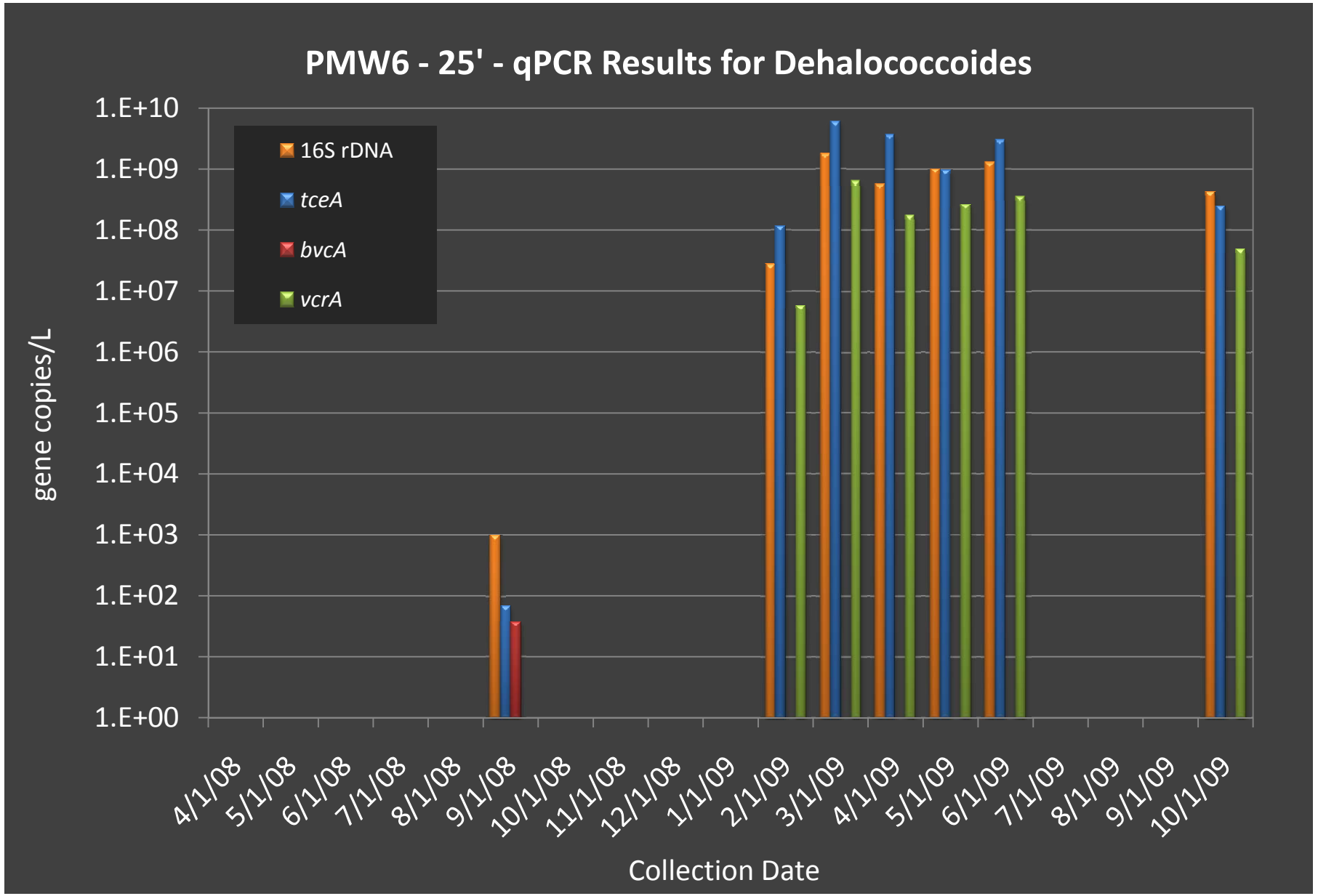
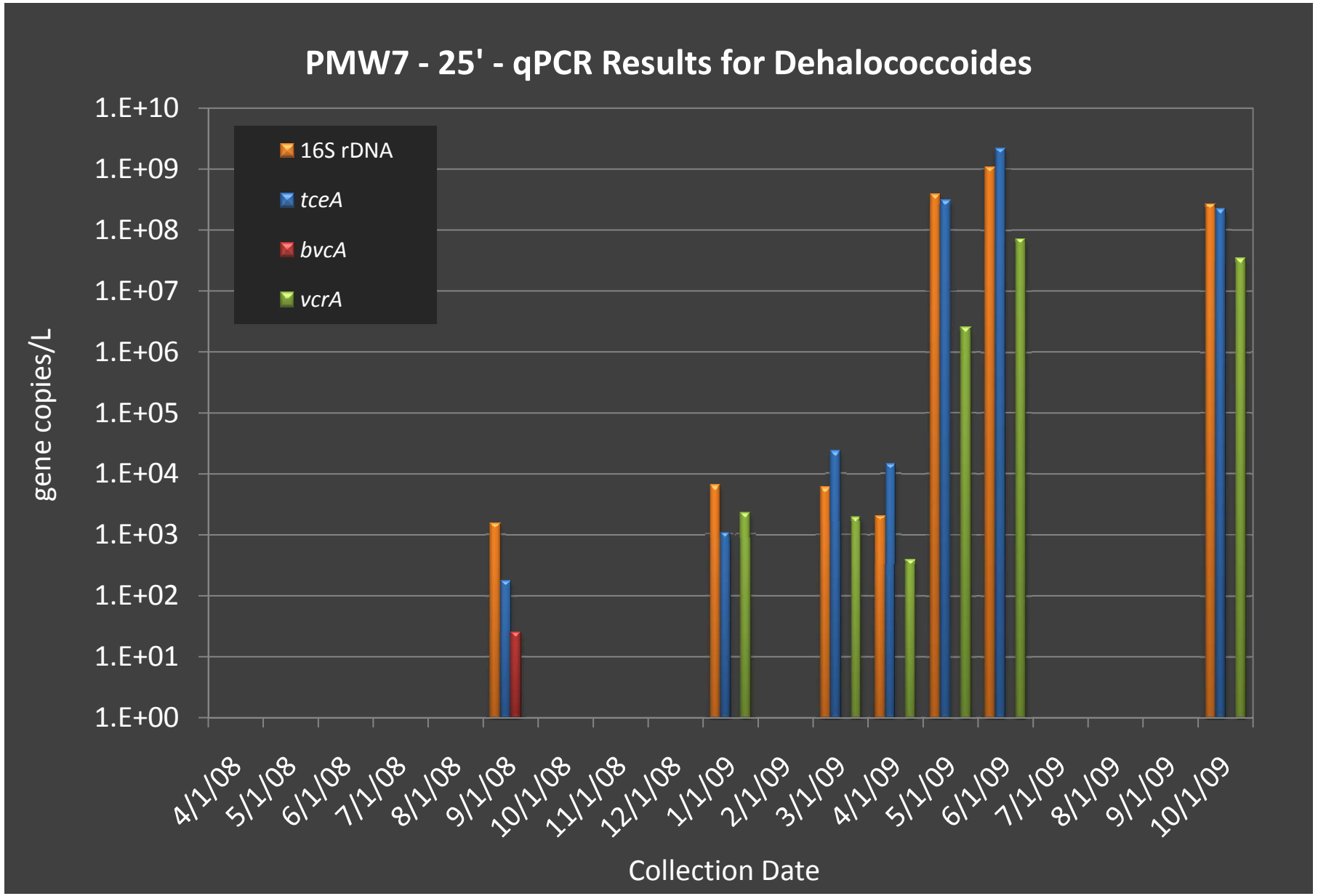
8/1/09
9/1/09
10/1/09
Collection Date

Seal Beach
Groundwater Bioaugmentation



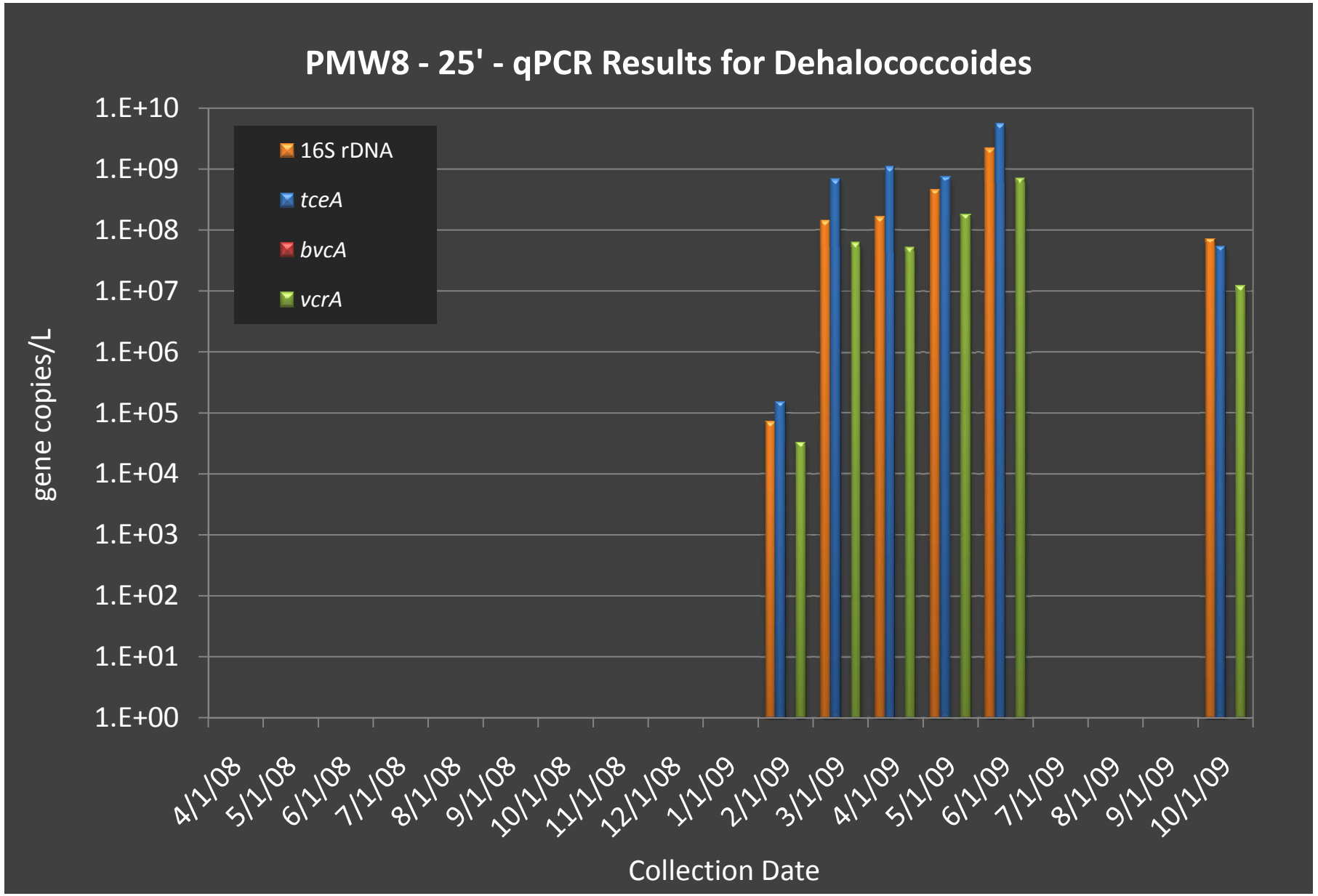
PMW6-25, DHC_Pas_Seal Beach_Oct 2009.xls

Seal Beach
Groundwater Bioaugmentation



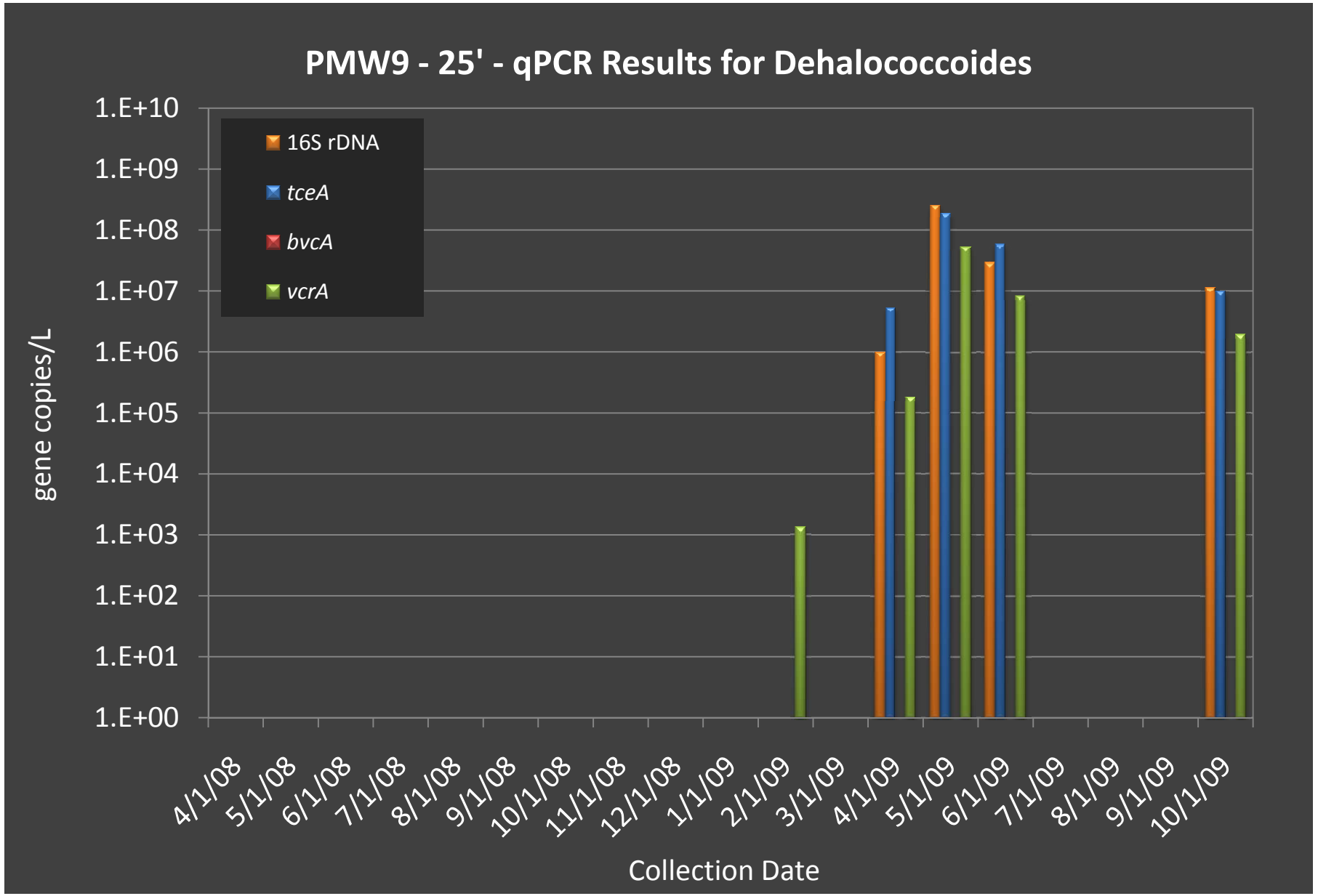
PMW7-25, DHC_Pas_Seal Beach_Oct 2009.xls

Seal Beach
Groundwater Bioaugmentation



PMW8-25, DHC_Pas_Seal Beach_Oct 2009.xls

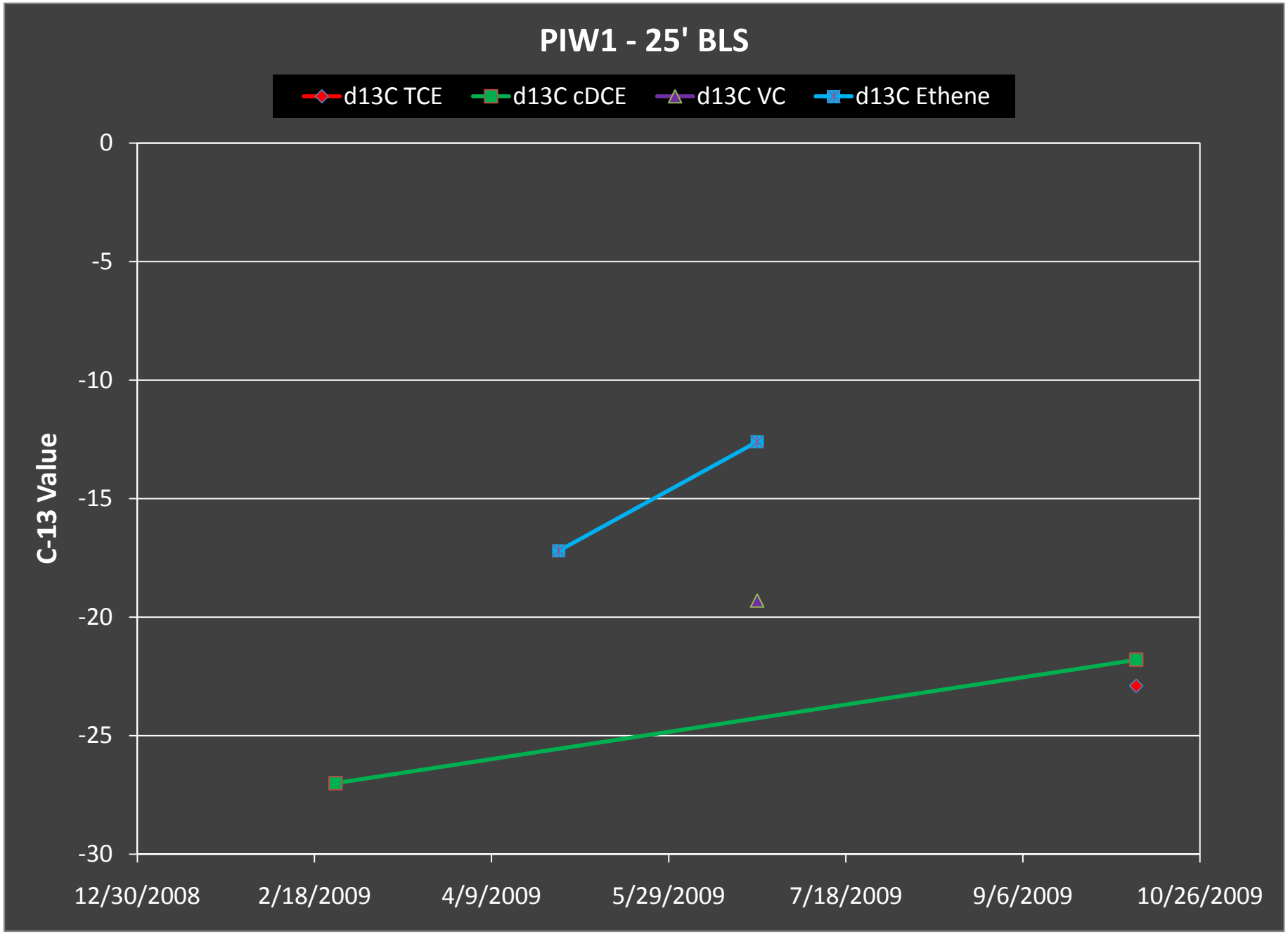
Seal Beach
Groundwater Bioaugmentation



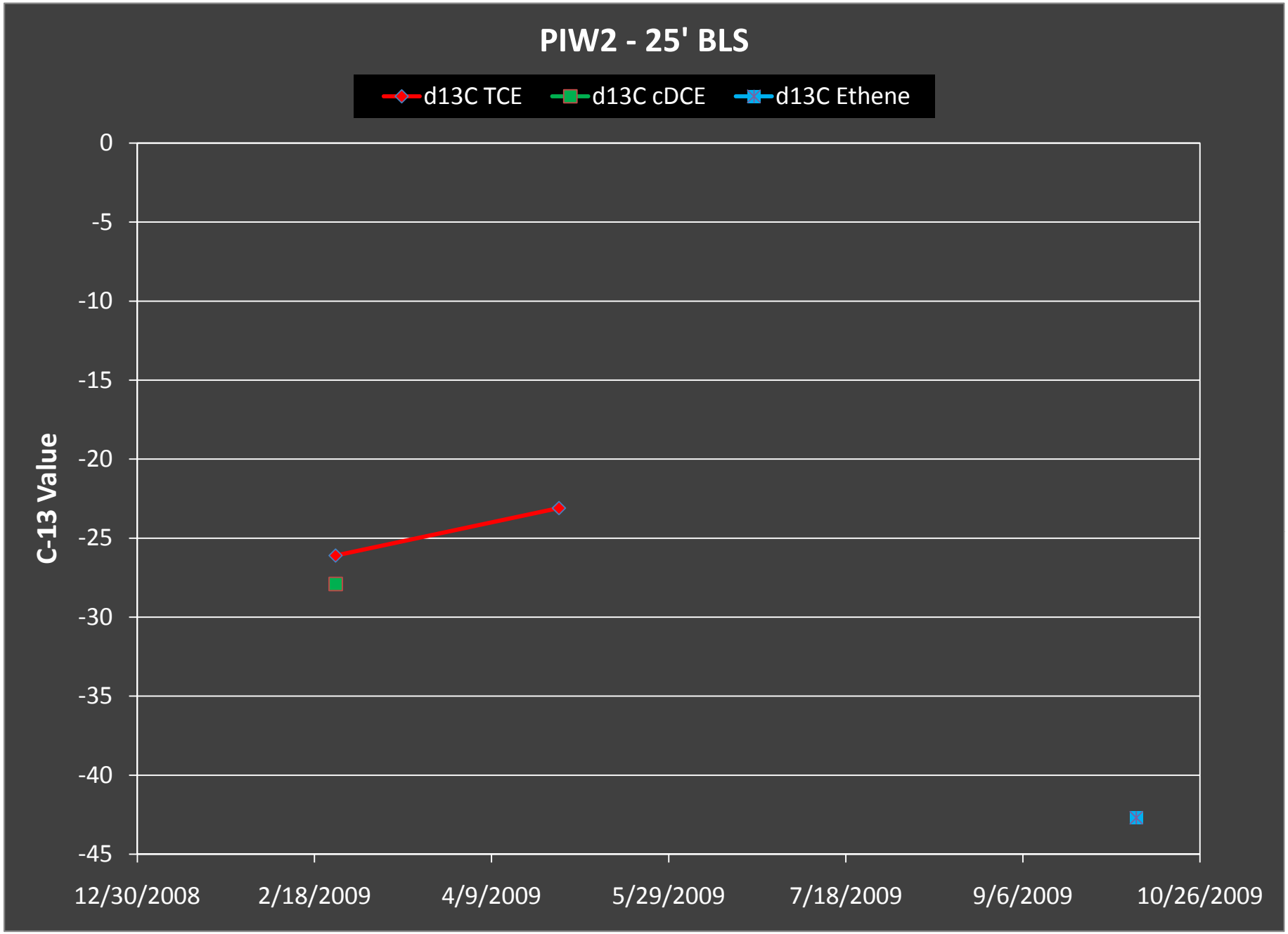
PMW9-25, DHC_Pas_Seal Beach_Oct 2009.xls

CSIA Results

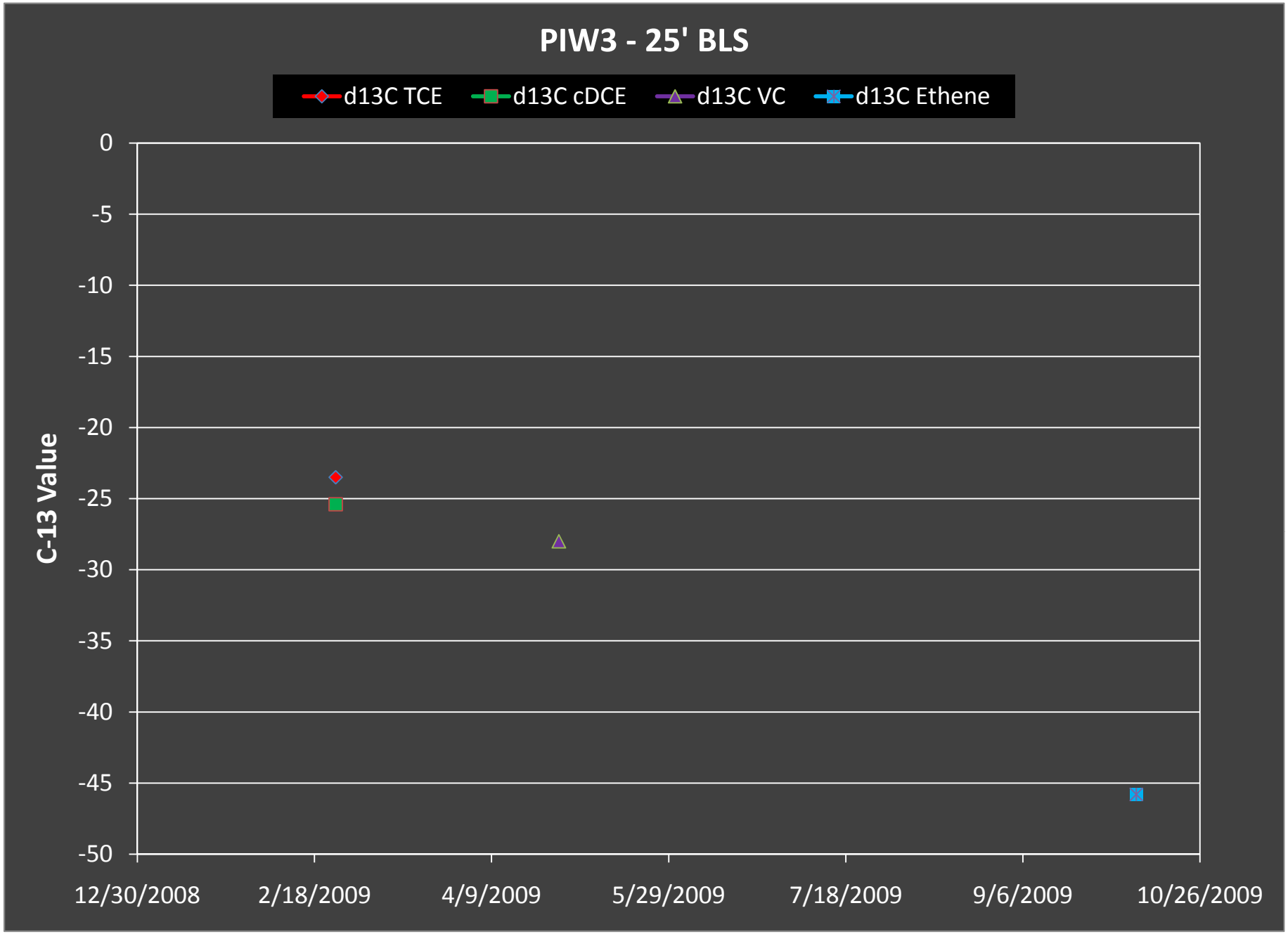
Seal Beach
Groundwater Bioaugmentation



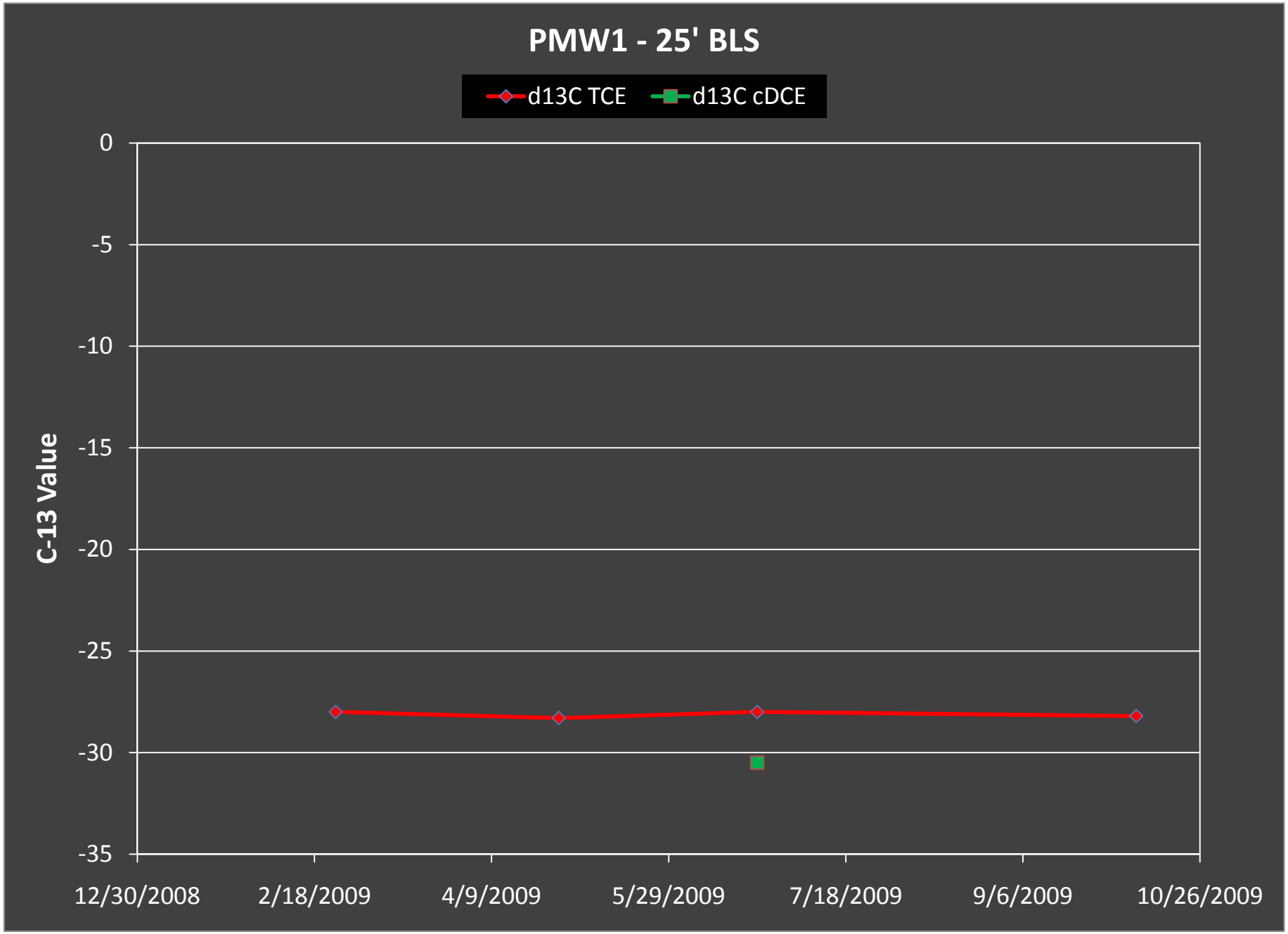
Seal Beach
Groundwater Bioaugmentation



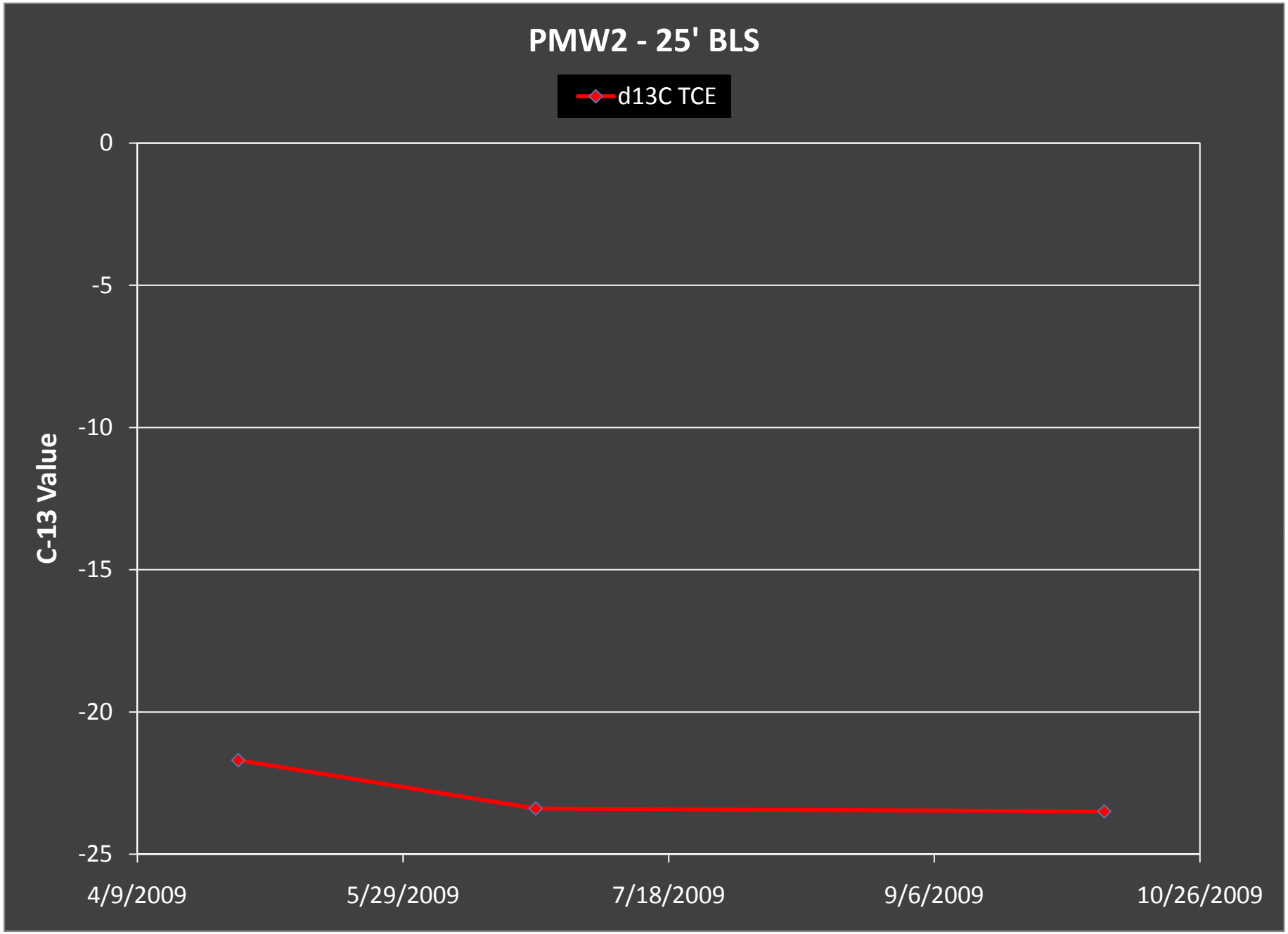
Seal Beach
Groundwater Bioaugmentation



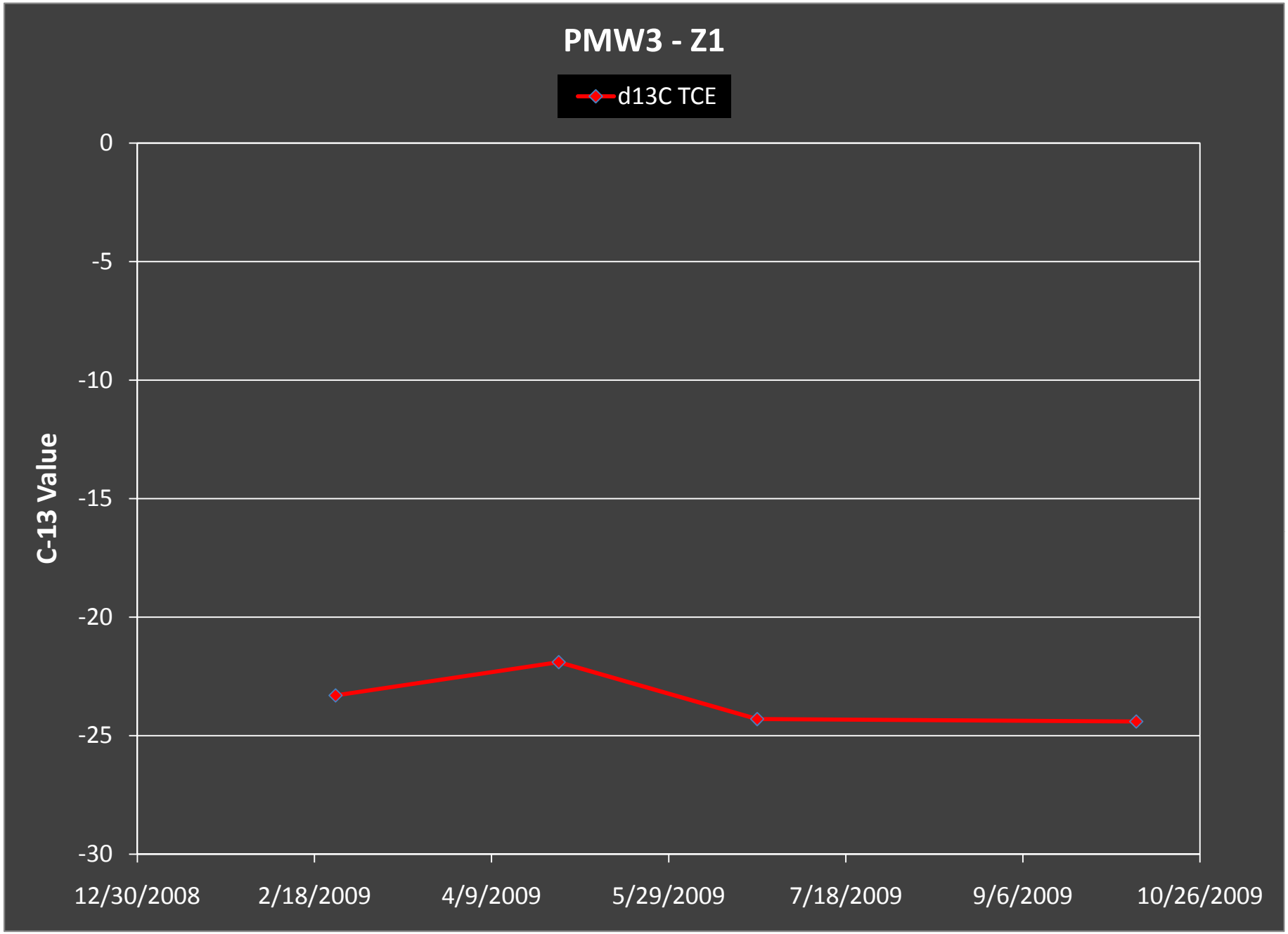
Seal Beach
Groundwater Bioaugmentation



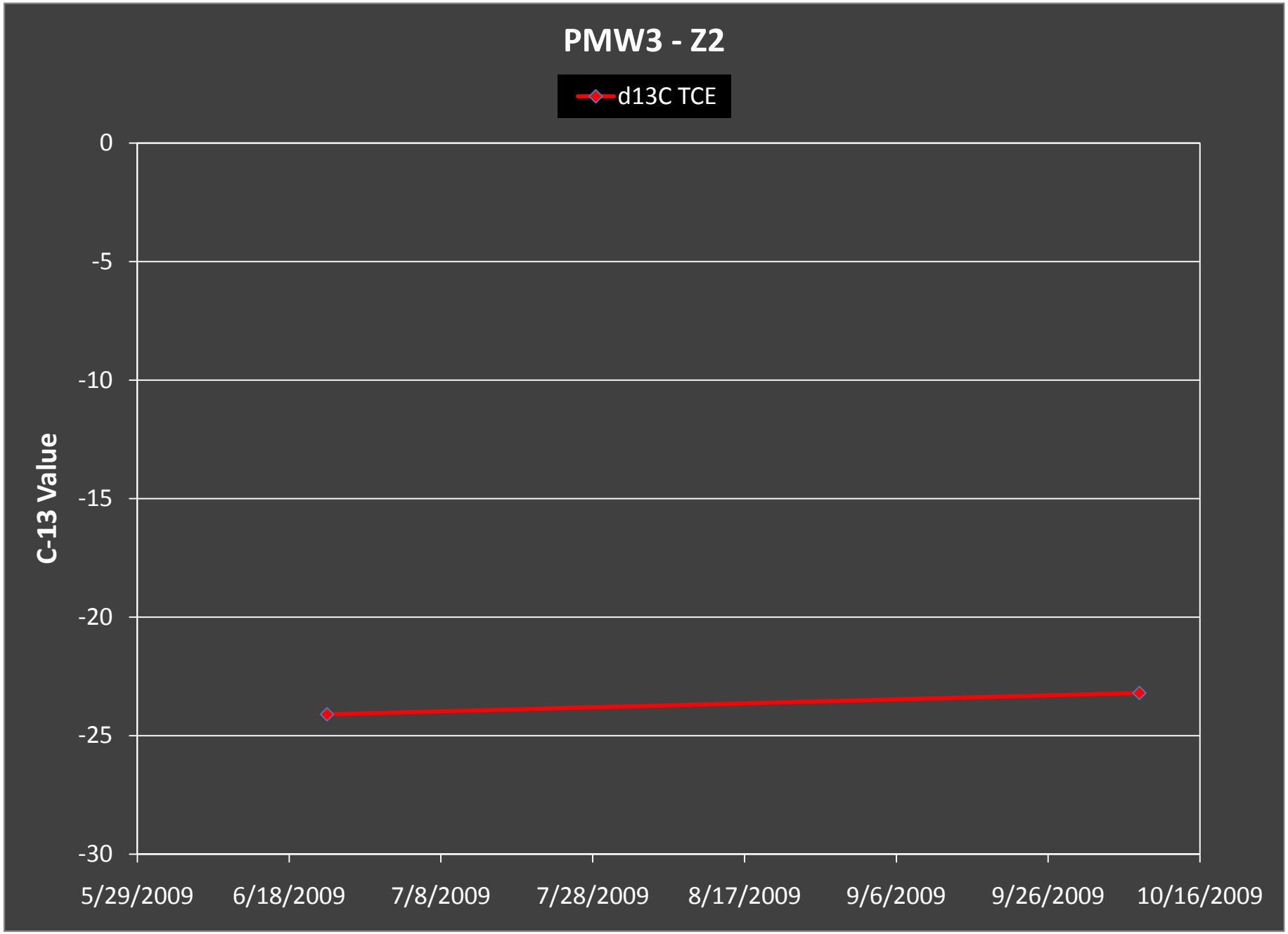
Seal Beach
Groundwater Bioaugmentation



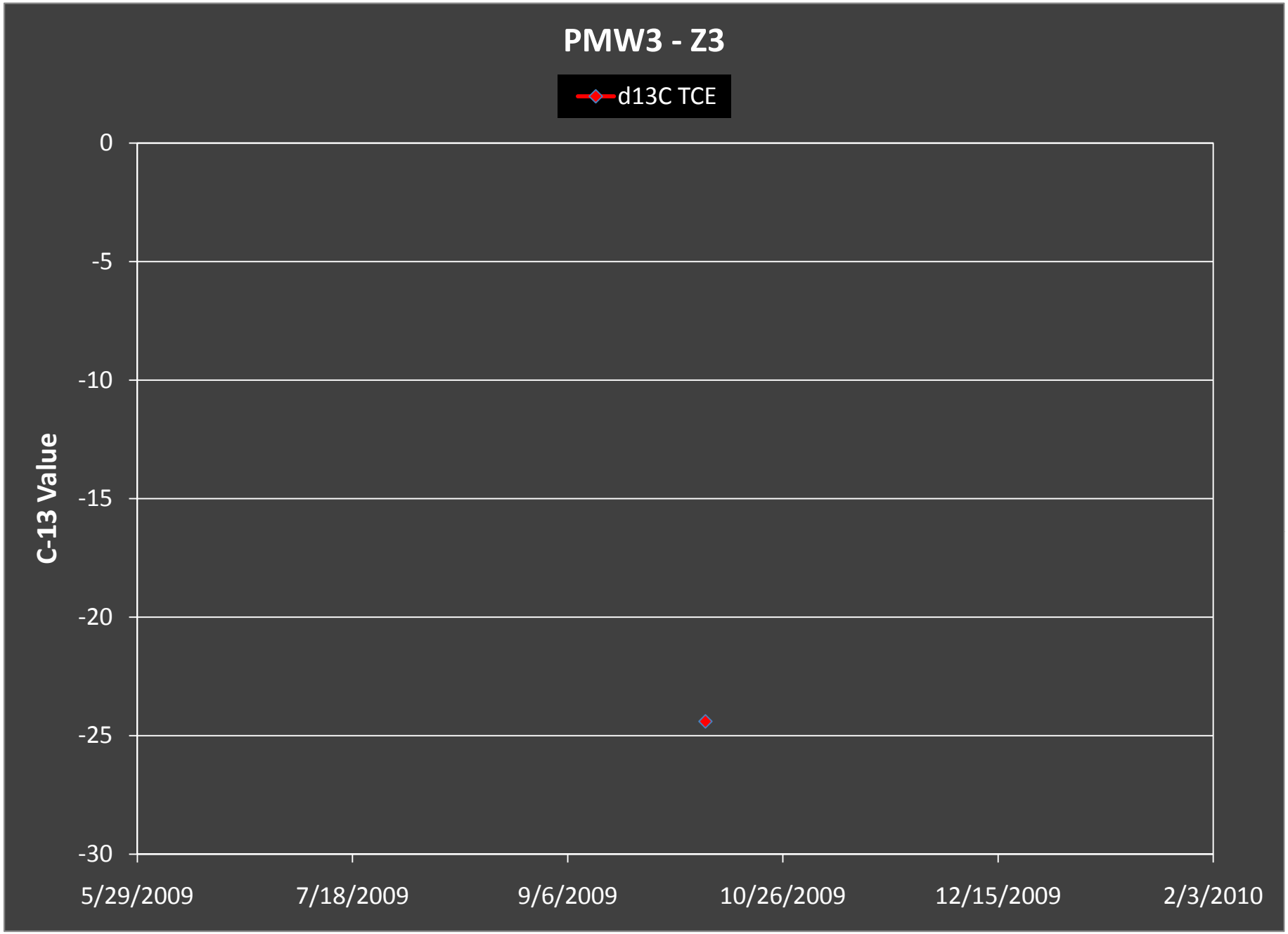
Seal Beach
Groundwater Bioaugmentation



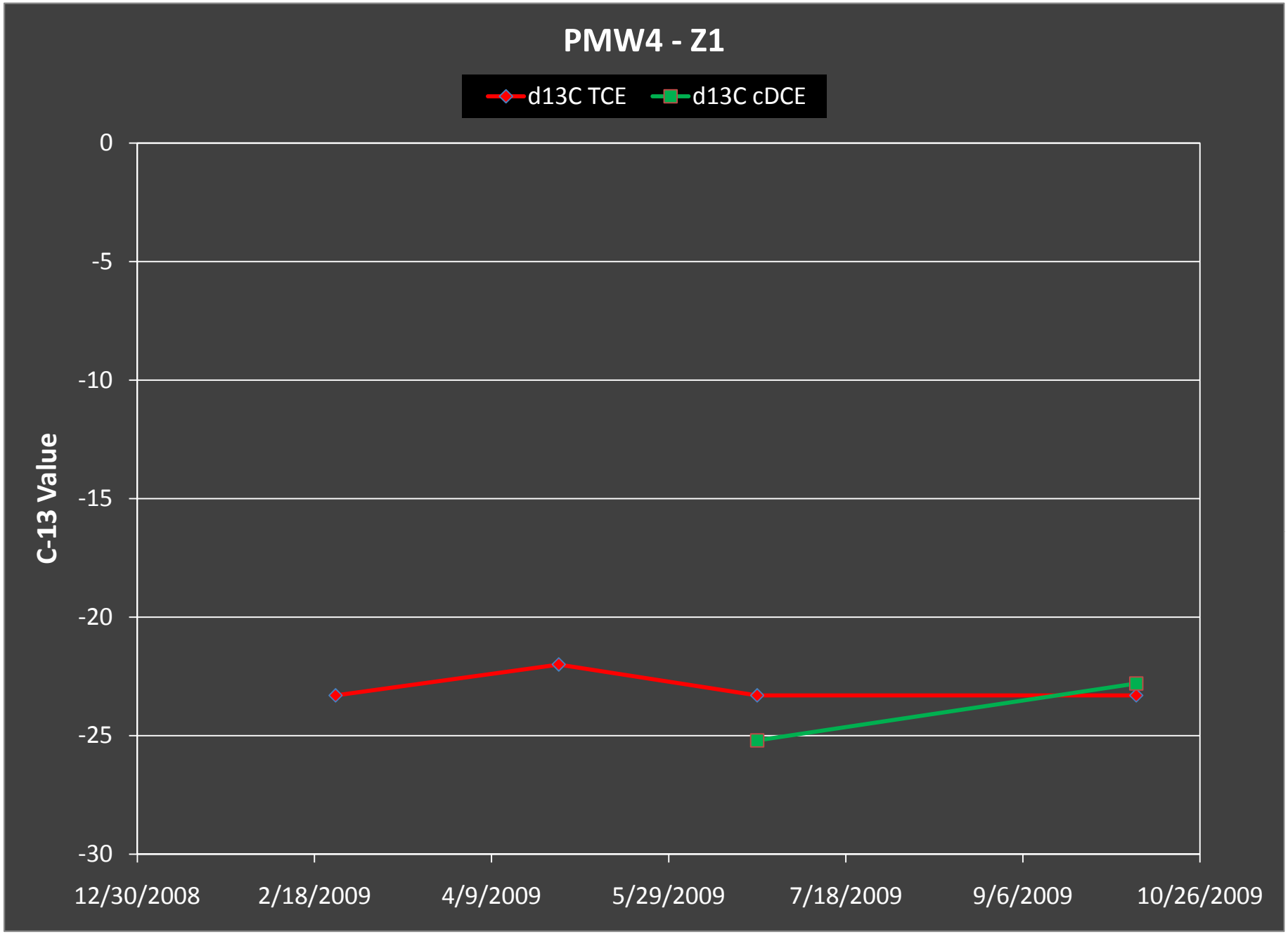
Seal Beach
Groundwater Bioaugmentation



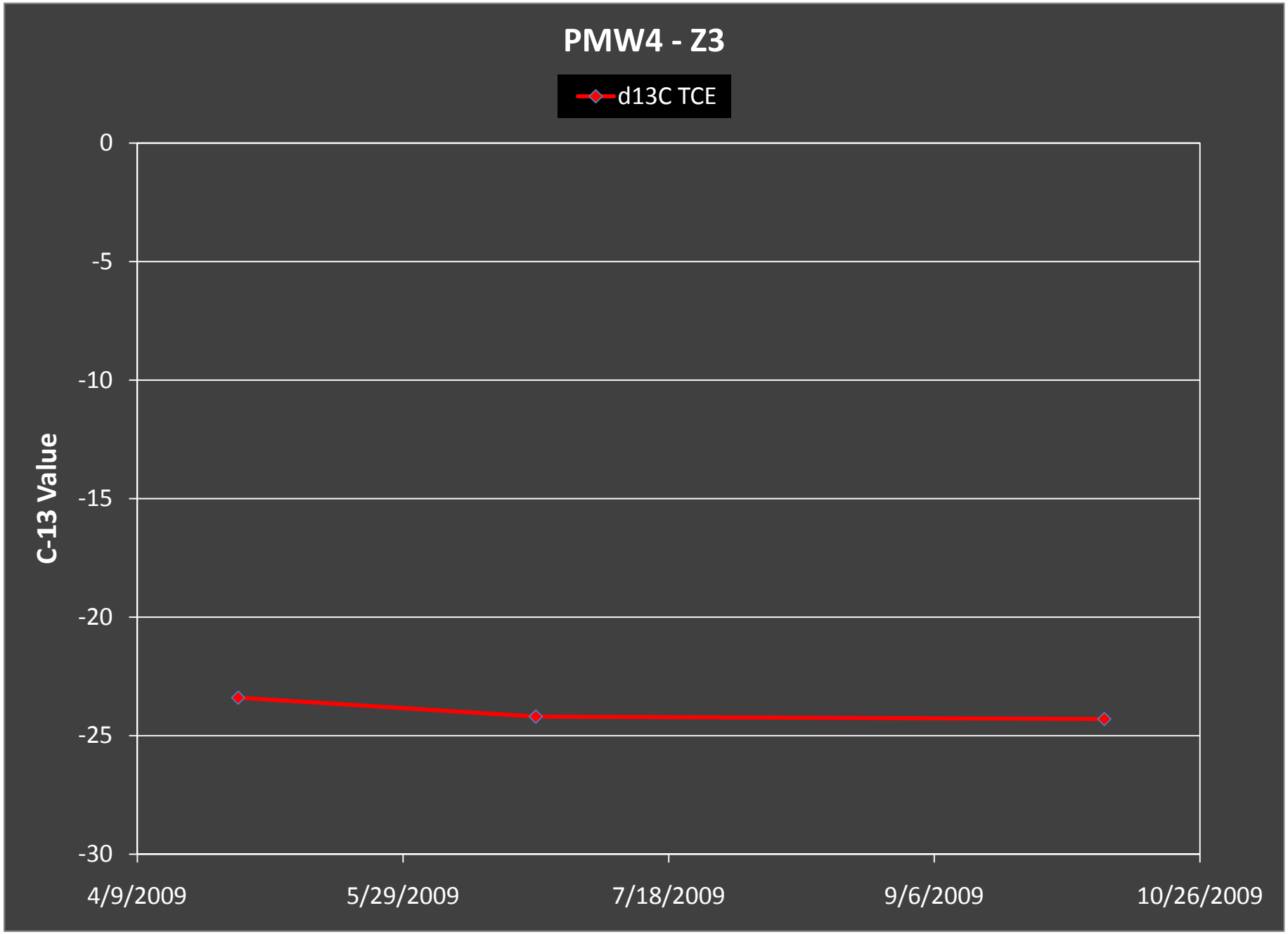
Seal Beach
Groundwater Bioaugmentation



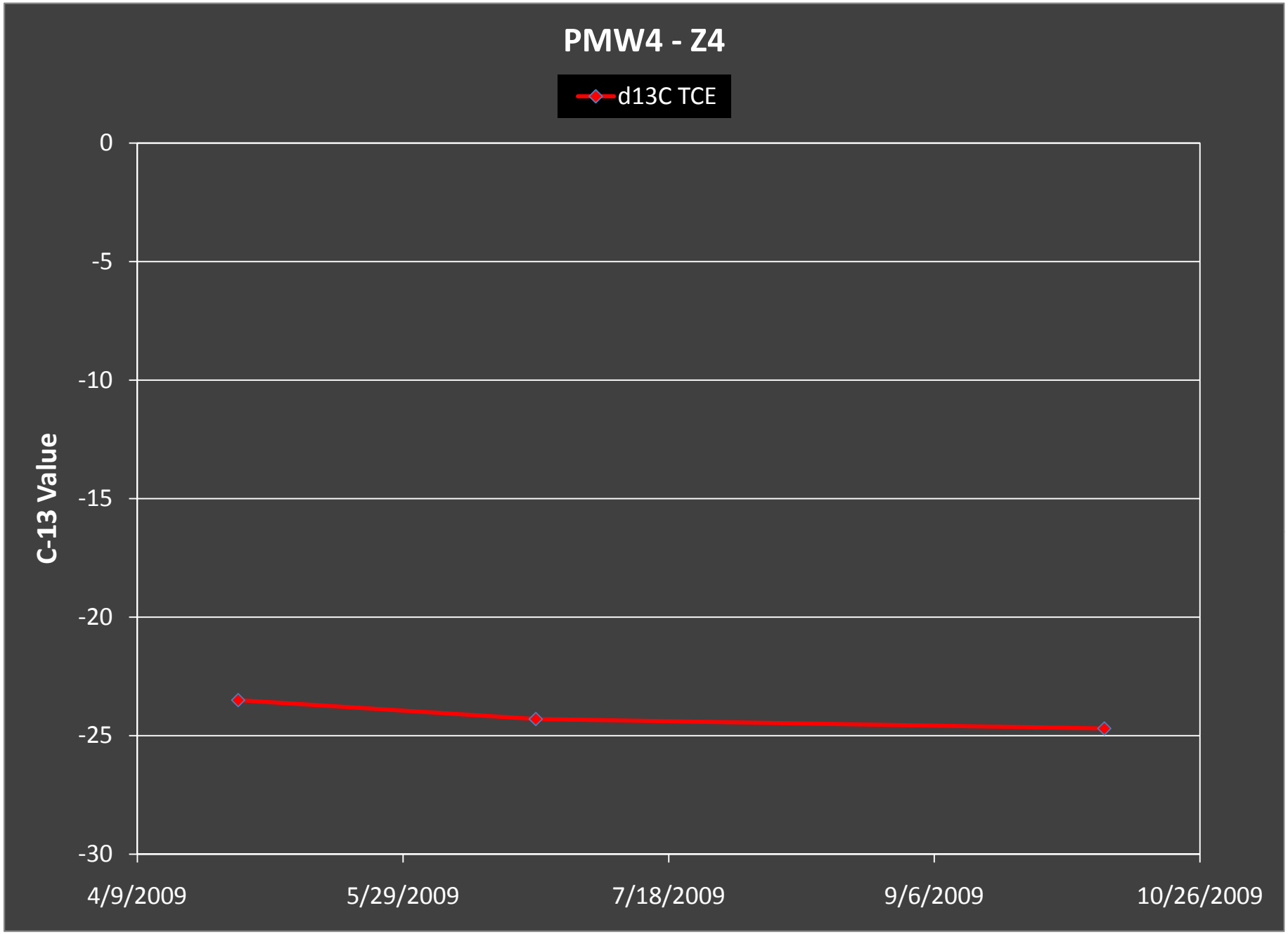
Seal Beach
Groundwater Bioaugmentation



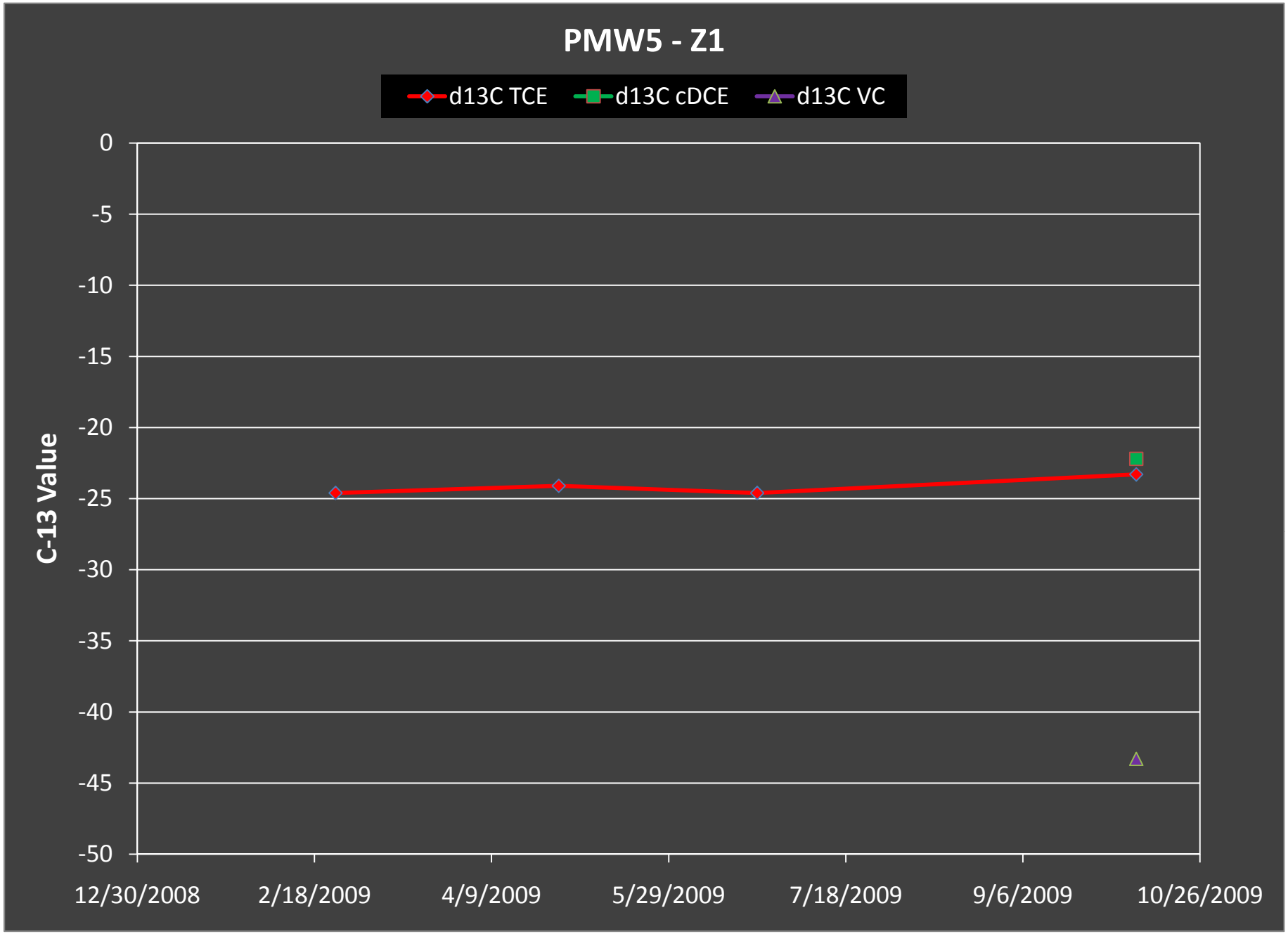
Seal Beach
Groundwater Bioaugmentation



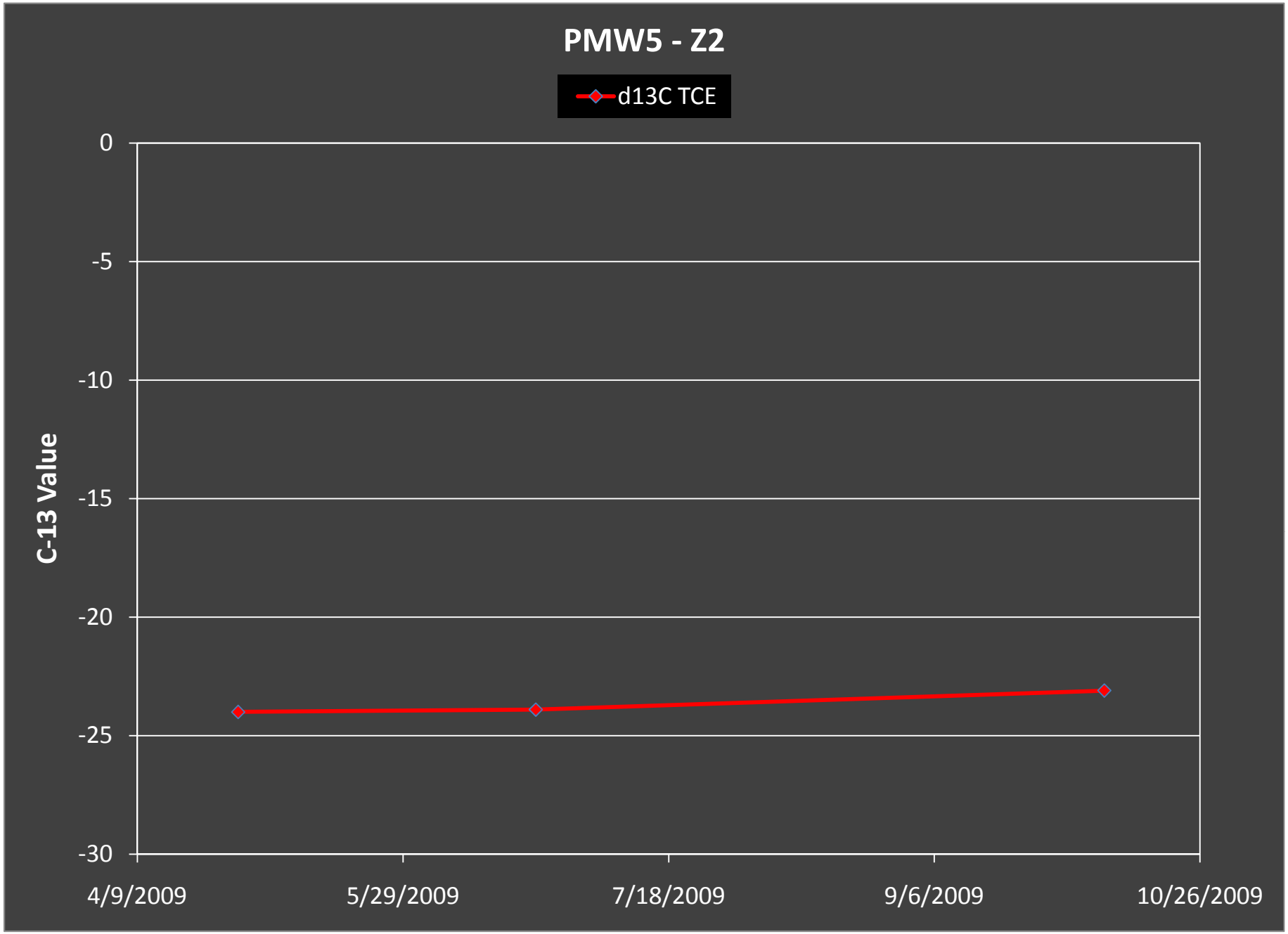
Seal Beach
Groundwater Bioaugmentation



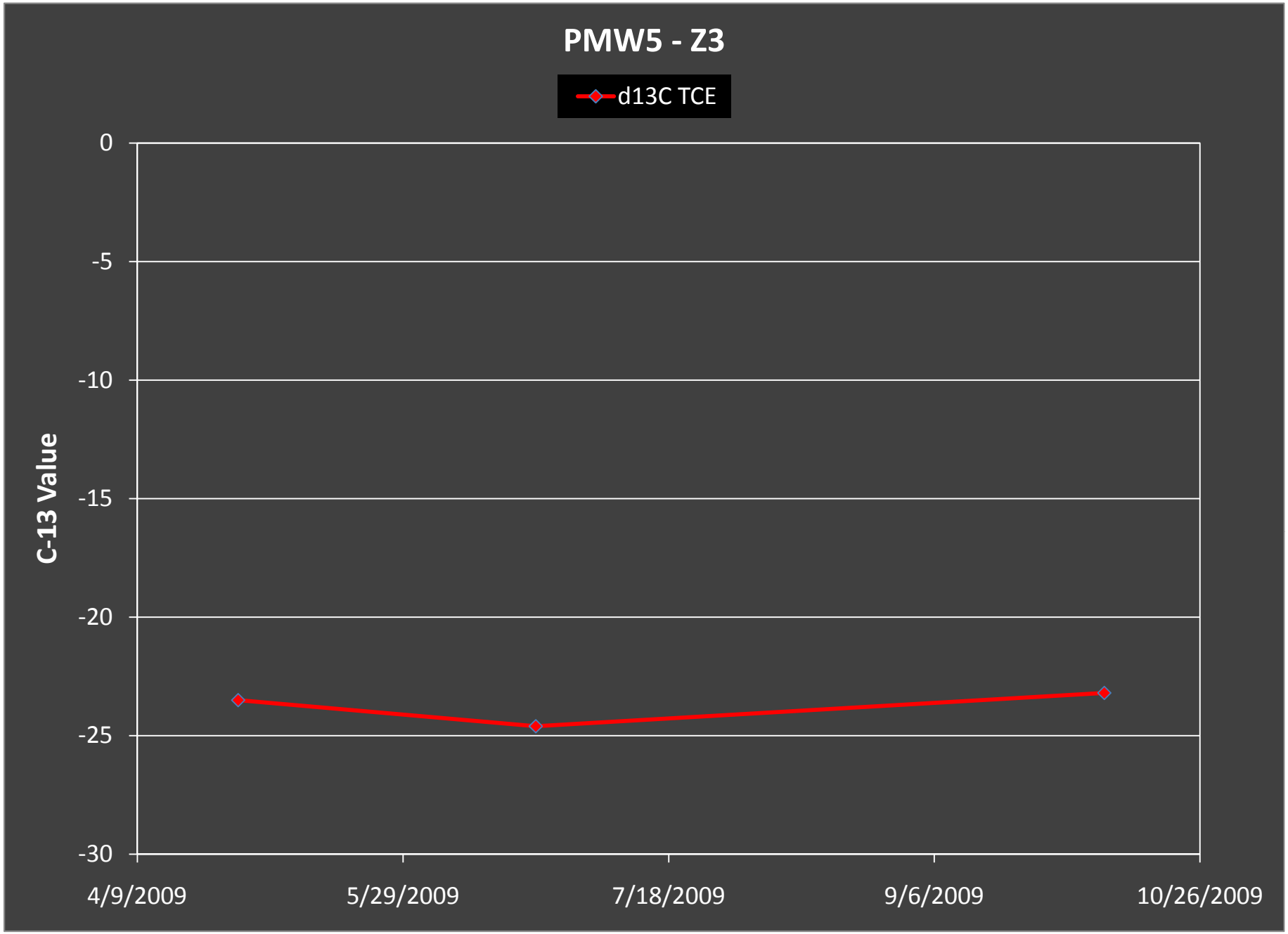
Seal Beach
Groundwater Bioaugmentation



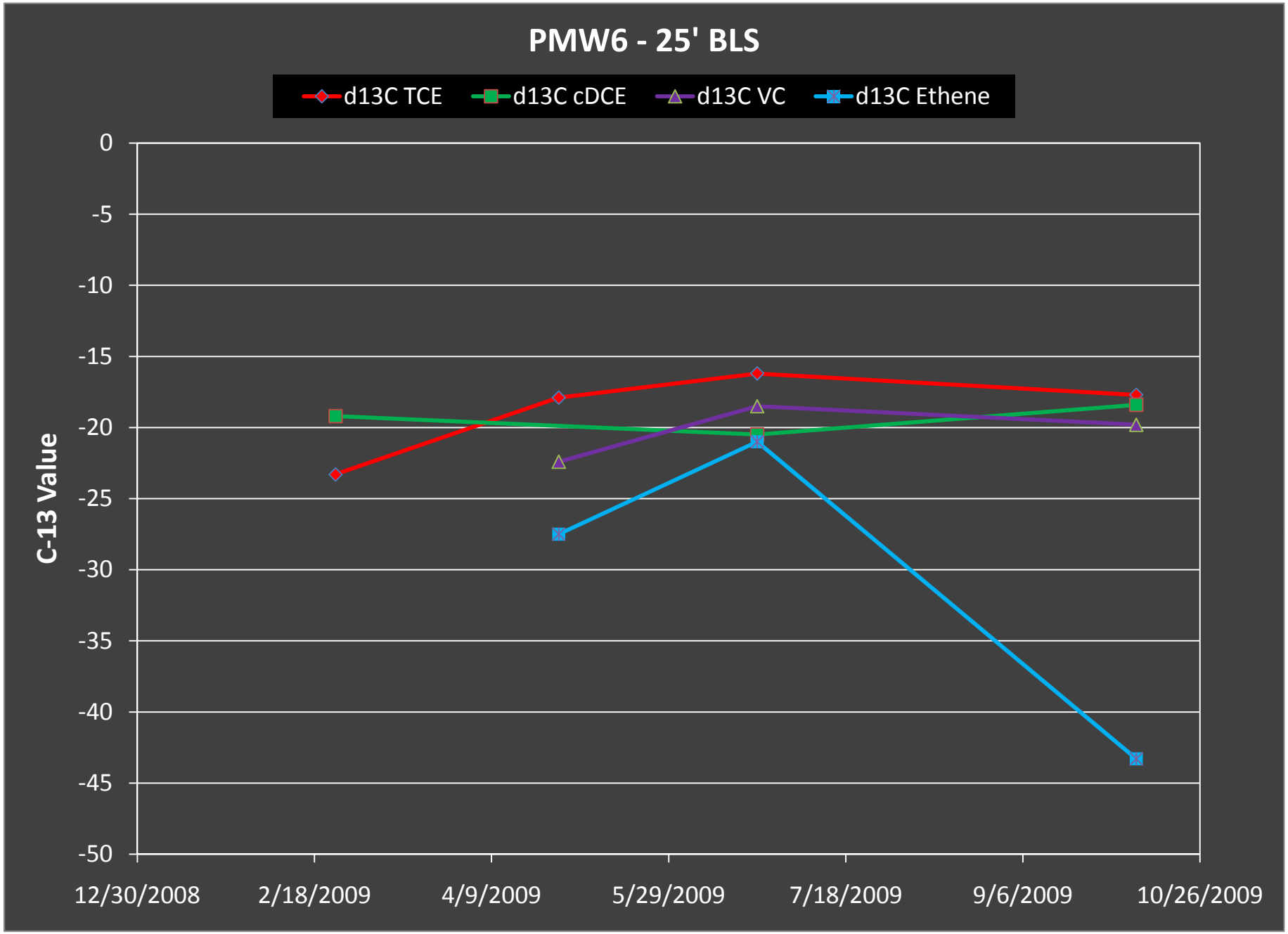
Seal Beach
Groundwater Bioaugmentation



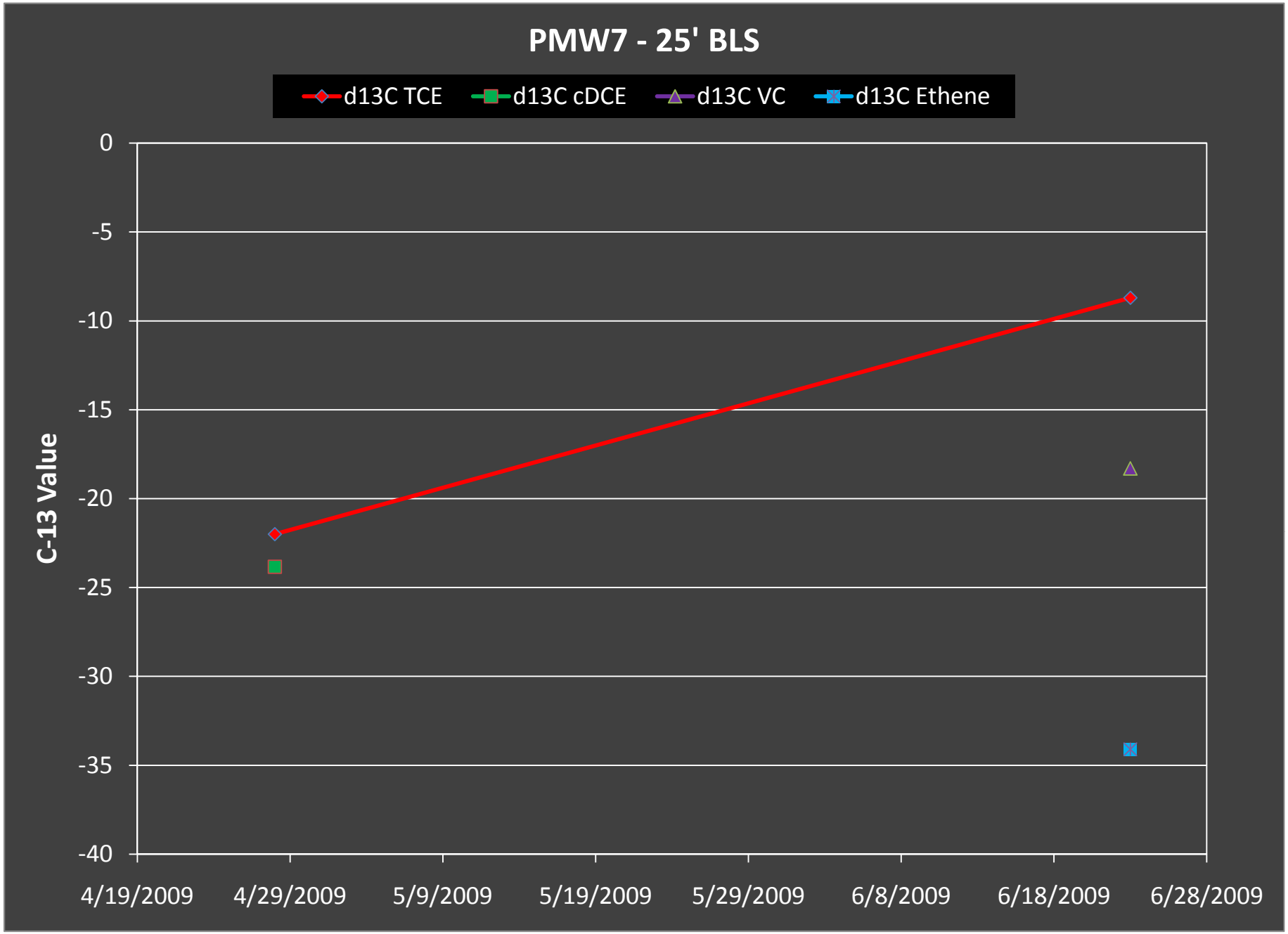
Seal Beach
Groundwater Bioaugmentation



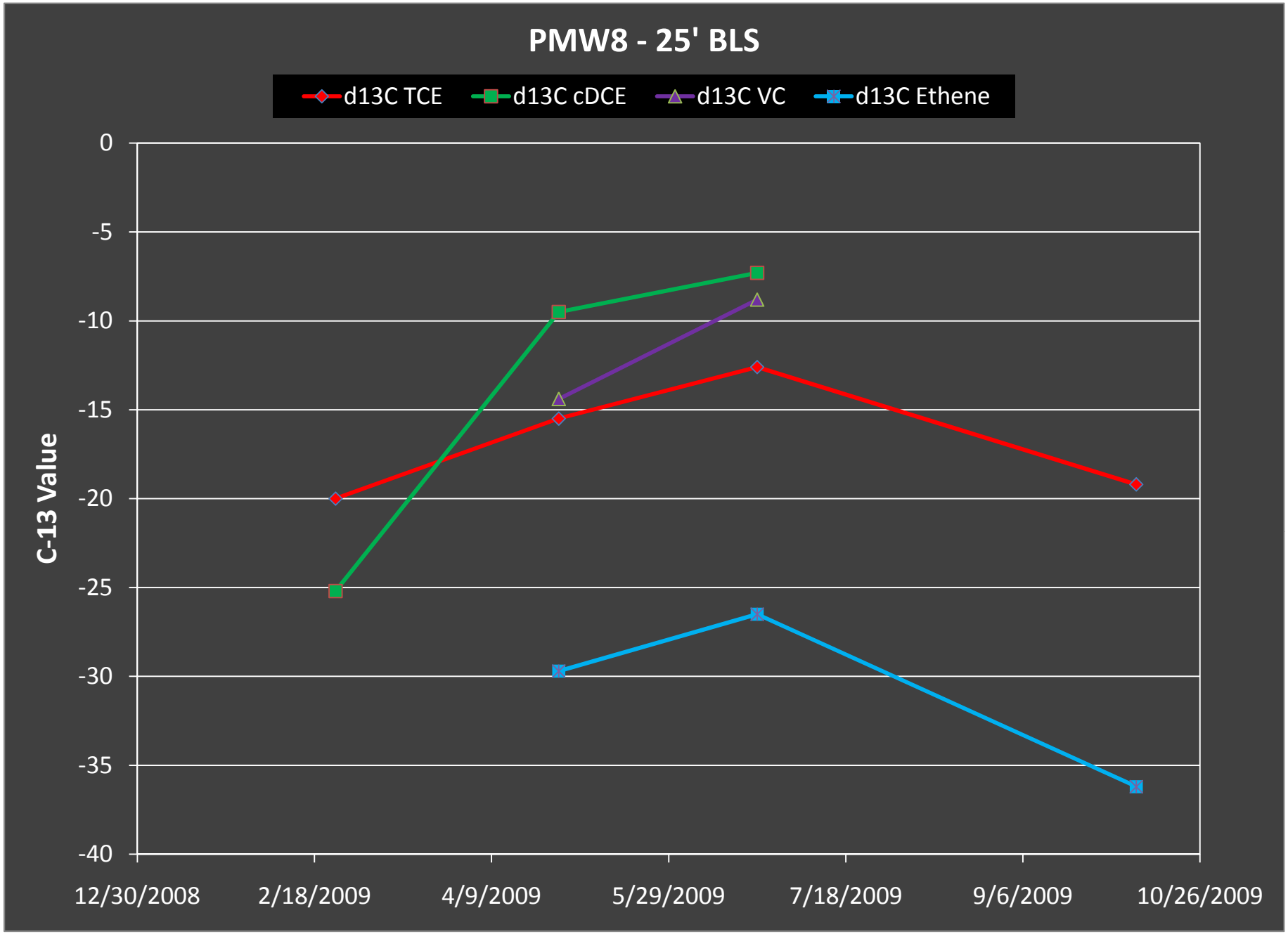
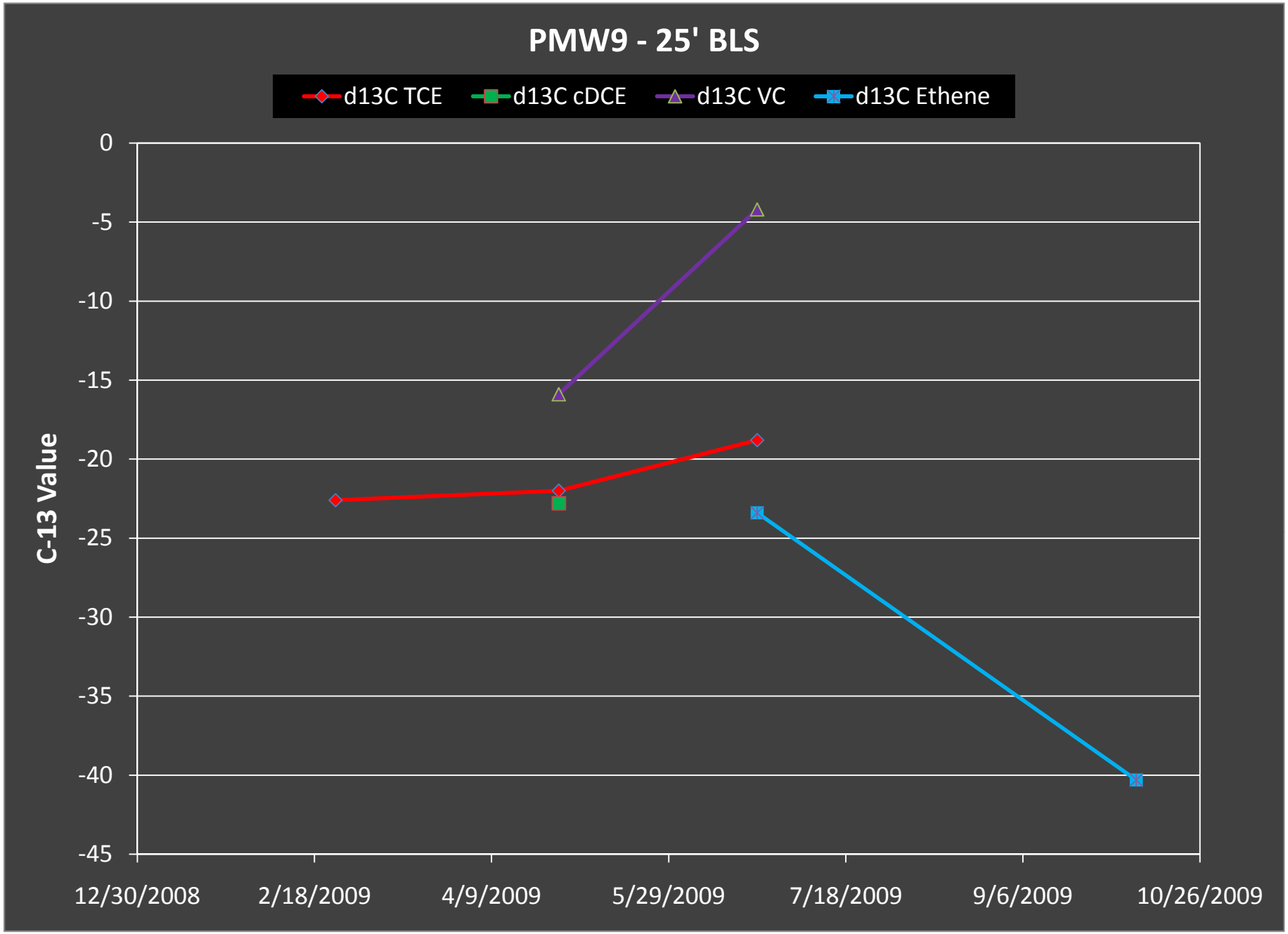
Seal Beach
Groundwater Bioaugmentation



Seal Beach
Groundwater Bioaugmentation



Seal Beach
Groundwater Bioaugmentation



Seal Beach
Groundwater Bioaugmentation